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COMPARISON OF THE GENERAL DYNAMICS GROUND CLOBBER ALGORITHM WITH THE GCAS AND LAWS ALGORITHMS

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FOR THE COMMANDER:

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Three ground avoidance algorithms were evaluated over a variety of mission profiles to determine their effectiveness in avoiding Controlled Flight into Terrain (CFIT) mishaps. Eight pilots flew nine data collection missions each while subjectively evaluating the system's nuisance warnings. During each mission one of the three algorithms was on-line while the other two were being flown off-line. This provided a mechanism to directly compare each algorithms' performance over identical flight conditions. There were 107 crashes in the experiment resulting in 107 crash plots used for the comparison.

The crash plots indicated no significant difference between algorithm performance with regard to crash frequency. The algorithms did differ slightly when performance was evaluated over specific flight regimes, to include diving into flat terrain, level flight into rising terrain, and diving into rising terrain. Subjective evaluation of nuisance warnings indicate significant philosophical differences between the algorithms. Keywords:

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I. INTRODUCTION

Although the Air Force accident rate in recent years has been at an all time low, many feel an even lower rate could be achieved by reducing the number of controlled flight into terrain (CFIT) accidents, which constitute the second largest category of Tactical Air Force (TAF) Class A mishaps. Air Force investigations concluded that between 1975 and 1981 there were 56 fighter and attack aircraft involved in CFIT accident mishaps. The United States Navy has attributed the loss of 317 aircraft to CFIT accidents between 1970 and 1984. Although the occurrence of CFIT could be greatly reduced in the tactical fleet by installing forward looking Terrain Following Radar (TFR) systems, such a solution would be prohibitively expensive and possibly unnecessary. Since a significant percentage of CFIT accidents occur during low level missions while flying over sloping terrain that is not particularly severe, it has been proposed that a less costly solution to the problem could be based on less complicated sensors (e.g., a radar altimeter system) that would cover a part of the CFIT envelope instead of all of it.

Such an approach has been highly successful on commercial airliners and some wide body military transports which are equipped with a Ground Proximity Warning System (GPWS). The CFIT accidents for commercial aircraft have in fact dropped to virtually zero since 1976, when GPWS use was mandated by the Federal Aviation Administration. However, the much more complex nature of tactical application cannot be accommodated by the system currently available in commercial and wide body aircraft.

In an effort to develop a Ground Collision Avoidance System (GCAS) for F-16 aircraft, General Dynamics has developed a "Ground Clobber" algorithm designed to provide a warning to the pilot in the event of an impending CFIT mishap. The F-16 System Program Office requested that the Crew Station Design Facility investigate General Dynamic's algorithm over a variety of tactical maneuvers.

II. BACKGROUND

In an effort to determine the capabilities of existing CFIT avoidance algorithms, the CSDF decided to evaluate three different algorithms: General Dynamics' Ground Clobber (GC) Algorithm, Cubic's Ground Collision Avoidance (GCAS) Algorithm, and Fairchild's Low Altitude Warning System (LAWS) Algorithm. In this section the focus will be on the similarities and differences of these three algorithms.

General Dynamics' GC Algorithm is the only one of the three evaluated that provided an alert visual cue to advise the pilot of an impending "pull-up" warning. The algorithm continuously compares aircraft height above the ground with the altitude required for dive recovery, predicting altitude loss during dive recovery as a sum of the following:

a. Altitude loss due to pilot response time.
b. Altitude loss during roll recovery.
c. Altitude loss during a 4-G pull-up.

The Ground Clobber Algorithm also has a 50 foot buffer resident within the system.

The Cubic GCAS Algorithm is the only one of the three algorithms evaluated that allowed the pilot to select set clearance plane. Such a feature allows the pilot to determine, at his discretion, an appropriate clearance altitude. This algorithm continuously compares the aircraft's present height above the ground with the altitude required for dive recovery and predicts altitude loss during dive recovery as a sum of the following:

a. Altitude loss due to pilot response time.
b. Altitude loss during roll recovery.
c. Altitude loss during a 5-G pull-up.
d. Altitude loss due to terrain rise during the pull-up.

The GCAS algorithm differs from the GC algorithm in two distinct ways. First, it is based on a 5-G pull-up, while the GC algorithm is based on a 4-G pull-up. Secondly, the GCAS algorithm calculates the altitude loss due to ground rise using a filtered estimation of the terrain slope directly below the aircraft. The GC algorithm does not estimate terrain slope. Further information on the mechanization of these algorithms can be found in Appendix A.

The LAWS algorithm differs in philosophy from either of the previous two algorithms. Based on maximum G's available rather than on a set G pull-up, this algorithm is inherently more aggressive than the prior two. The G's available are based upon the weight, wing area, coefficient of lift, and dynamic pressure. The maximum G calculated is limited by an "if" statement which can be changed to accommodate any value of maximum. For this evaluation, the G limit was not changed from the A-10 value of 9 G's. A built-in minimum altitude of 90 feet provides a pull-up warning at any instance the radar altitude is 90 feet or less. (This minimum design altitude was tied to the filtered radar altimeter, and under certain conditions lagged behind the radar altimeter. This resulted in the masking of some MDA warnings, but had no effect on the report's crash

data.) The LAWS Warning Algorithm also includes a predictive warning calculation. This predictive portion issues a warning based on a prediction of the time necessary for recovery based on pilot reaction time, flight path angle, bank angle, airspeed, minimum design altitude, and terrain slope. A major difference between the LAWS algorithm and the other two algorithms is the extensive inhibit logic used. Appendix A contains additional information on the LAWS algorithm mechanization and predictive warning inhibits.

III. PURPOSE

The overall objective of this simulation study was to evaluate the Ground Clobber algorithm in a variety of tactical scenarios. The study was specifically designed to provide data which could be used to:

a. Evaluate the adequacy of the algorithm to provide a warning in sufficient time for a pilot to recover in a variety of CFIT scenarios.

b. Compare the GC Algorithm to the LAWS and GCAS Algorithms.

c. Evaluate the impact and incidence of nuisance warnings generated by each of the three algorithms.

d. Assess pilot reaction to each of the three algorithms.

IV. METHOD

APPARATUS

Experimental Facility. This applied experimental research was conducted at the Crew Station Design Facility (CSDF), an Air Force flight simulation facility which belongs to the Aeronautical Systems Division (ASD) of Air Force Systems Command (AFSC) at Wright-Patterson AFB Ohio. The personnel at the CSDF conduct human engineering studies in support of a variety of System Program Offices (SPOs). The facility currently includes an F-16, an A-10, and a KC-135 cockpit simulator and an extensive computer complex. Its two visual systems are capable of simulating day and night time visual, LANTIRN, and FLIR.

F-16 Simulator. The CSDF F-16 flight simulator was used as the test vehicle for this study. The simulator itself was constructed using a salvaged single-seat F-16 cockpit truncated from in front of the forward windscreen, to approximately fifty-seven inches behind the canopy hinge. The undercarriage has been removed, and the base of the simulator sits on wheels. The simulator does not employ a motion base. The cockpit controls and displays are configured to the F-16 Multi-National Staged Improvement Program (MSIP) Block 40 design. This all-digital design includes two 4 x 4 inch multi-function displays (MFDs), a wide field-of-view (WFOV) raster video head-up display (HUD), an integrated control panel (ICP), a data entry display (DED), hands on stick and throttle controls, centralized flight instruments, and the LANTIRN avionics suite (terrain following, radar altimeter, FLIR). The stick, throttle, and flight instruments are actual F-16 components. However, all of the other instruments, controls, and displays are simulated using locally available equipment. The aft section of the simulator, in the area formerly occupied by fuel cells, now contains the microprocessor racks which encompass the advanced simulator technology (AST) interface. The microprocessors operate the controls and displays, while two fifty-pin ribbon cables connect the simulator to the mainframe computers which perform the aerodynamic calculations. The combination of F-16 real and simulated instrumentation, the fully operational controls and displays, the realistic visual terrain and HUD, and the actual cockpit work together to create a high fidelity replica of the F-16 MSIP cockpit. The aerodynamic model is the same one that is used for aircrew training, and its validity has been demonstrated in a number of prior experiments. The primary flight controls, the terrain model visual system, and the simulated HUD were the main components used in this study. A synthesized voice warning system was used to transmit digitized warnings (pull-up, pull-up) to the pilot for each warning event.

Computer Complex. The computer complex at the CSDF consists of one Gould Concept 32/8780 and four Gould Series 32/7780 mainframe computers, PDP11/34 and 11/35 computers, and various graphics computers. All aircraft aerodynamics and aircraft systems were computed on the mainframe computer complex. Performance data collected on each mission were taken

from the mainframe computers and recorded on magnetic tape for subsequent review and analyses.

Visual System. An out-of-the-cockpit visual scene was provided using a closed circuit TV system from a modified Link SMK-23 moving terrain model. Each of the two belts replicates a 23 x 15 nautical mile section of central Pennsylvania. The landscape was carved from foam, using a digitized data base in a computer driven milling machine. The foam was glued to the 15 foot high moving canvas belt, painted, and finished with individually applied cultural features. The particular section of Pennsylvania used for the terrain boards was chosen because it provided a wide variety of terrain in a relatively small area. The belt itself moves in a north or south direction, while the camera moves east or west on a gantry. The head of the camera can also move in and out relative to the boards, simulating altitude. This provides simulated aircraft visual parameters of 360 degrees continuous heading, 360 degrees of continuous roll plus or minus 120 degrees of pitch, and 50 to 4000 feet of altitude. The visual apparatus consists of a Cohu high resolution, low light level TV camera and a Farrand optical probe. The picture is transmitted to a Conrac 1000 line black and white TV monitor through a beam splitter to a parabolic mirror with a focal length of 54 inches. This combination gives the pilot approximately a 48 degree forward field-of-view (FOV) collimated to appear at infinity.

Head-up Display. The LANTIRN HUD simulation is created by using the model employed to verify the production design. This model not only requires the pilot to look in exactly the same place in the aircraft, but also within the same area and around the same obstructions. The control panel was built and interfaced through software programming to provide full control of the HUD symbology. A Vector General symbol generator displays the caligraphic symbology, while a PDP 11/34 maps and controls the HUD's position. The Gould mainframe computers send the flight parameters to the PDP computer to enable it to position the symbology within the raster video scene so that the pilot can use the HUD and the imbedded symbology to control the simulator.

Experimenter's Console. The experimenter's console provides controls and displays for mission setup, simulator operation, data collection equipment, and various control and display mechanization options. For this evaluation there were three options available to the experimenter to change simulator position and attitude. One option allowed the console operator to move the simulator forward 3000 feet in the flight plan to simulate a late pop on weapons delivery runs. When this occurs in the real world, the pilot finds himself outside optimum delivery parameters; the target is more difficult to find, and corrections require a steeper than normal delivery angle. This feature was used on Missions 15 and 17 to complicate the delivery task.

Another option allowed the operator to decrease simulator altitude in increments of 1000 feet. This was used on Mission 16 to simulate entry into dynamic maneuvers at a lower than expected altitude. This led to unexpected CFIT warnings in attitude and flight path conditions approaching the limits of system operation, and in some cases, disorientation.

The final option, dealing with simulator control, required the use of

a joy stick on the console to operate in series with the pilot's control stick. With this capability, the experimenter could change aircraft pitch and roll attitudes during periods of pilot distraction to simulate entry into unusual (or unexpected) attitudes. This control feature was used effectively during low level navigation and high "G" turning flight when pilots were instructed to read authentication and alphanumeric cards.

SUBJECTS:

A total of eight pilots participated in the study. Five were operational pilots from the Tactical Air Command (TAC), and three were pilots from Wright-Patterson AFB with previous Tactical experience in the low level environment. All the pilots, except one from TAC, had previous F-16 experience. The pilots had varying amounts of flight time in the F-16 as indicated in Table 1. The pilots arrived over a course of a month, with an average of two pilots participating each week.

TABLE 1. Pilot Experience

Subject Number	Total flying time (hrs.)	Total F-16 Time
1	3100	700
2	1600	300
3	500	100
4	3000	200
5	2000	600
6	2800	0
7	2950	600
8	1700	350

EXPERIMENTAL DESIGN:

The experimental design was a repeated measures three by three design, with algorithm and mission type as the independent variables. There were three algorithms: GCAS, LAWS, and GC. There were also three separate types of missions (descriptions follow). Each pilot acted as his own control. Subjects were randomly assigned to the conditions.

Missions. Three missions were selected to test the algorithms. The overall objective in designing the profiles was to subject the pilot to a variety of conditions representative of those encountered in tactical fighter operations, with specific emphasis on the kinds of situations reported in CFIT incidents. A brief description of each mission follows; additional details are provided in Appendix B.

a. Low Level Navigation/Pop-up Deliveries (Mission 15). This mission was flown at 300-500 feet above the terrain at approximately 480 knots ground speed. Some segments of the route were flown over relatively level terrain between ridges, simulating typical terrain masking operations. Other segments required ridge crossings and flight over rough terrain. Three targets located along the route of flight were used for pop-up weapons deliveries. Pop-ups were initiated 20 seconds prior to the target to allow 20-30 degree dive deliveries. The experimenter could advance the simulator in the pop so that the aircraft would be outside normal delivery parameters in the pull-down.

b. Instrument Meteorological Conditions (IMC) Maneuvering (Mission 16). This mission consisted of a series of aerobatic maneuvers flown under IMC. These maneuvers required the pilot to recover from relatively extreme pitch and bank attitudes similar to what he might encounter during unusual attitude or spatial disorientation incidents. During some of the maneuvers (the loop, split S, and Cuban 8), the experimenter adjusted simulator altitude 3000'-4000' to cause early and unexpected altitude alarms.

c. Range Mission and Hard Turns at Low Altitude (Mission 17). The first half of this mission consisted of three runs on the same target from two different headings - simulating a low level range familiarization flight. Like Mission 15, delivery maneuvers consisted of a 30 degree straight-ahead pop at 20 seconds prior to the target, a climb to 4000 feet Mean Sea Level (MSL) and a roll to inverted flight for the pull down to a 20-30 degree dive. Bomb release was briefed to be completed at 2500 feet MSL.

The second half of Mission 17 was flown over essentially level terrain at 480 kts. in a figure eight pattern between two steerpoints. At each steerpoint passage, the pilot initiated a 5 'G' turn of about 210 degrees to simulate defensive maneuvering at low level (300'-500'). During the turns, pilots were asked to read a series of numbers and letters from a card located on the canopy over head to simulate checking their 6 o'clock position for other aircraft. Reductions to aircraft altitude were made by the experimenter during the turns on this mission to further complicate the recovery task.

Test Procedure. When the pilots arrived to participate in the study, they were asked to fill out a personal data questionnaire (Appendix C). They were then given a general briefing on the facility and experiment, and a specific briefing on each of the three algorithms (GC, GCAS, and LAWS). They then moved to the vault for ground school on the F-16 simulator, and were given an opportunity to fly a training mission for practice to conclude the initial half day period. In the following half and full day, the pilots flew 10 missions in which data were

collected. The three algorithms over the three missions accounted for nine of these missions. The tenth mission consisted of an enhanced GC algorithm flown over just Mission 15. The last half day allowed the experimenter to complete any additional or make-up missions required, to de-brief the pilots, and to administer the final questionnaire. A detailed schedule of events for each pair of pilots is in the Appendix C.

Dynamic Evaluation. After completing the simulator orientation training, flying the practice mission, the pilots returned to the pilot briefing room where they took part in a mission planning session. Mission briefings prior to each data collection flight covered the overall mission scenario, specific objectives of the mission, altitudes, speeds, times, etc.... Pilots were also provided with a mission setup checklist and a strip map of the route of flight when appropriate. The subject pilot then moved back to the simulator to conduct the actual experiment. After the pilot completed cockpit setup actions, reviewed the mission, checked the headset audio, closed the canopy, and indicated that he was ready to start the run, the simulator and data recording equipment were activated and the mission was started. Voice communications were held to a minimum during each evaluation run and were limited to responding to the pilot's questions or, as was the case with Missions 15 and 17, recording his assessment of the validity of algorithm warnings, since these were the only missions where he was in a position to assess the validity of the warning. On these missions pilots were asked to rate the warning as valid or invalid (either late or early).

Data Collection and Measurement. A variety of flight parameters were recorded on the mainframe computers for each mission. Table 2 lists the flight parameters which were recorded, their unit of measurement, and their range. At the conclusion of each individual mission, the pilot completed a short questionnaire. An overall questionnaire was administered at the end of the experiment.

TABLE 2. FLIGHT PARAMETERS

FLIGHT PARAMETERS	UNIT OF MEASUREMENT	RANGE
Pitch Attitude	degrees	± 90
Roll Attitude	degrees	± 180
"G" Load	"G"	-3 to + 10
Flight Path Angle	degrees	± 90
Pitch Rate	degrees/second	± 45
Absolute Altitude	feet	0 to 1000
Barometric Altitude	feet	0 to 6000
Heading	degrees	0 to 360
Roll Rate	degrees/second	± 75
Yaw	degrees	± 45
Terrain Angle	degrees	± 60
GCAS Triggered Pull-up Time	seconds	discrete
GC Triggered Pull-up Time	seconds	discrete
LAWS Triggered Pull-up Time	seconds	discrete
Altitude at Pull-up Alarm (all three)	feet	discrete
Altitude Clearance at Pull-up (all three)	feet	discrete
Engine RPM	%RPM	idle to 95
Groundspeed	knots	0 to 600
True Airspeed	knots	0 to 600
Angle of Attack	degrees	
Stick force	lbs	discrete
Time from Signal to Change in Stick Force	seconds	

Following each simulated mission, a short debriefing session provided an opportunity for the experimenter and evaluation pilot to discuss simulator and algorithm operation. During these sessions the experimenter recorded pilot comments on the algorithm operation as it applied to the

mission just flown. The post mission questionnaire also evaluated missed warnings, early or late warnings, and nuisance warnings. These questionnaires were later compiled by algorithm type and are described in the results section. Questions and their summary results are included in Appendix C.

V. RESULTS

The parameters described in Table 2 allow reconstruction of the flights for more definitive evaluation. The critical flight parameters were plotted as time histories for each maneuver resulting in a crash. The data were plotted from a period of ten seconds prior to the crash to five seconds after the crash, to show beginning and ending conditions for each event for subsequent analysis and assessment of pilot performance.

Since the three algorithms were resident in the system and all three could be run concurrently, warnings were generated off-line for the two algorithms not in use for a particular mission. Using this technique, warnings from two and sometimes all three systems under essentially identical flight conditions could be evaluated off-line.

EXPERIMENTAL PERFORMANCE DATA

Two series of data were collected during the course of this experiment. In the first series, baseline data were collected from a single pilot, under controlled conditions.

Baseline Dive Recovery Performance

a. Basic Algorithm Performance. In an effort to establish some baseline data on each of the three algorithms, one set of runs was made against a perfectly level terrain base at - 2.5 degrees, - 10 degrees, -20 degrees, -30 degrees and -40 degrees flight path angles, first in a wings level attitude, and then at 50 degrees of bank. In order to obtain consistent data, power was set to approximate that required to maintain 480 KCAS at the start of each descent. This resulted in increasing speed during each run with the rate of speed increase higher at the higher flight path angles. All runs were flown manually so slight variations in flight path angle and bank occurred. The data shows, however, that these variations were, for the most part, less than 1 degree. Table 3 gives the warning altitudes and recovery altitudes in feet for each of the given conditions. Table 3a shows wings level results and Table 3b shows results from 50 degree bank descents.

TABLE 3. Baseline Dive Recovery Performance

TABLE 3a. Wings Level

	GC			GCAS			LAWS		
FPA DEG	WARN	RECOVER	G	WARN	RECOVER	G	WARN	RECOVER	G
-2.5	109	88	3.7	92	53	3.5	90	43	6.3
-10	628	419	5.3	501	276	6.1	266	40	5.1
-20	1973	1360	6.4	1353	597	7.4	736	123	8.0
-30	3647	2529	7.1	2593	1409	7.8	1366	198	8.6
-40	5794	3943	7.1	2477	731	8.2	2303	570	8.9

TABLE 3b. 50 degrees bank

	GC			GCAS			LAWS		
FPA DEG	WARN	RECOVER	G	WARN	RECOVER	G	WARN	RECOVER	G
-2.5	100	83	3.3	123	75	3.9	90	34	7.8
-10	647	418	4.7	633	394	5.6	413	175	6.4
-20	2129	1425	5.3	1649	990	6.3	880	249	6.7
-30	3740	2370	7.1	2741	1544	5.9	1489	436	7.0
-40	5929	3731	6.2	4509	2216	6.8	2482	372	6.9

Note in the tables that warning altitudes for each algorithm are fairly repeatable. Comparing the three algorithms, LAWS consistently provided warnings at lower altitudes both with and without bank angle. This in turn led to lower recovery altitudes. Ground Clobber typically provided the highest warning/recovery altitudes of the three, with recovery altitudes as high as 3943 feet.

Maximum "G" attained on each run was included in the tables to place recovery altitudes in proper perspective. Obviously, considerable variation in altitude loss in a recovery occurs with variations in max "G" and rate of "G" onset.

Note that in most cases system design "G" forces were exceeded during some part of the recovery. As explained earlier in this report, the Ground Clobber Algorithm is based on a 4-G recovery, GCAS on 5-G and LAWS on as much "G" as the pilot can get. The limited "G" algorithms (GC and GCAS) are more consistent with F-16 stores limitations in that they are based on a 4-5 "G" maneuvering recovery. LAWS, on the other hand, is designated more as a last chance recovery warning and requires the use of more "G". In this context, experience with the systems will show that LAWS will usually lead to exceeding stores "G" limits.

b. Latest Algorithm Comparison. Subsequent to the formal evaluation, personnel from Cubic Corporation arrived to collect additional performance data and to make modifications to their basic GCAS algorithm. On the day before they left, we were asked to check out what turned out to be a fairly significant recovery algorithm change. In order to measure and record the effects of this change, we flew the same series of controlled descents using the new algorithm. Results of these runs are shown in Tables 4a and 4b. We have included in these Tables the same Ground Clobber and LAWS data shown previously to allow the reader to compare performance across the three systems.

Table 4. Recovery Comparison with Latest GCAS Algorithm

TABLE 4a. Wings level/flat earth

FPA	GC			GCAS			LAWS		
(-DEG)	WARN	RECOVER	G	WARN	RECOVER	G	WARN	RECOVER	G
2.5	109	88	3.7	151	103	3.3	90	43	6.3
10	628	419	5.3	422	212	5.0	266	40	5.1
20	1973	1360	6.4	909	206	6.4	736	123	8.0
30	3647	2529	7.1	1222	199	7.2	1366	198	8.6
40	5794	3943	7.1	2095	283	5.5	2303	570	8.9

TABLE 4b. 50 Degree Bank/flat earth

FPA	GC			GCAS			LAWS		
(-DEG)	WARN	RECOVER	G	WARN	RECOVER	G	WARN	RECOVER	G
2.5	100	83	3.3	154	112	3.6	90	34	7.8
10	647	418	4.7	445	132	4.7	413	175	6.4
20	2129	1425	5.3	1021	234	5.8	880	249	6.7
30	3740	2370	7.1	1696	276	6.3	1489	436	7.0
40	5929	3731	6.2	2303	484	6.0	2482	372	6.9

Note that in these Tables the modified GCAS algorithm now closely parallels LAWS performance, where previously it was quite similar to Ground Clobber.

Another recent modification to GCAS is a type of reasonableness check that requires three consecutive iterations of the algorithm prior to issuing a warning. This is similar in some respects to the 0.5 sec delay

proposed for Enhanced Ground Clobber and is intended to prevent nuisance warnings triggered by flight over irregular terrain.

Another modification delays warnings when the aircraft is in near level flight with less than 1 G. This was done to further reduce the number of nuisance warnings during ridge clipping. From what we have seen thus far, this has been effective when the pilot is, in fact, ridge clipping. The disadvantage of course is that it further reduces valid warnings if the pilot pushes too early topping a ridge, or if "G" is reduced to less than one in near level flight over level or slowly rising terrain.

SCATTER PLOTS

The performance data used to generate the plots were obtained from the experimental missions flown by the eight subject pilots. In the first series of plots, vertical velocity was recorded for each warning along with the total altitude lost during recovery. Three plots resulted, one for each of the algorithms. As expected, the altitude loss increased with increasing vertical velocity in all three cases (Figures 1, 2, and 3). Focusing on the lines of best fit in each figure does not indicate that any of the algorithms perform uniquely. The GCAS figure does show more dispersion of data points, especially at lower vertical velocities. This could, however, be attributed to a variety of factors to include potentially higher bank angles or warnings over differing terrain profiles. It is important to realize that each warning may represent very different flight and terrain conditions. The figures nonetheless provide comparative trend data.

In the second series of plots (Figures 4, 5, and 6), flight path angle was recorded for each warning along with the total altitude lost during recovery. Once again the lines of best fit have a positive slope or increase from left to right as expected. The unique cluster of warnings at the low flight path angles in Figure 4 may be indicative of a nuisance warning problem in this regime (i.e., a small amount of altitude is lost with each warning).

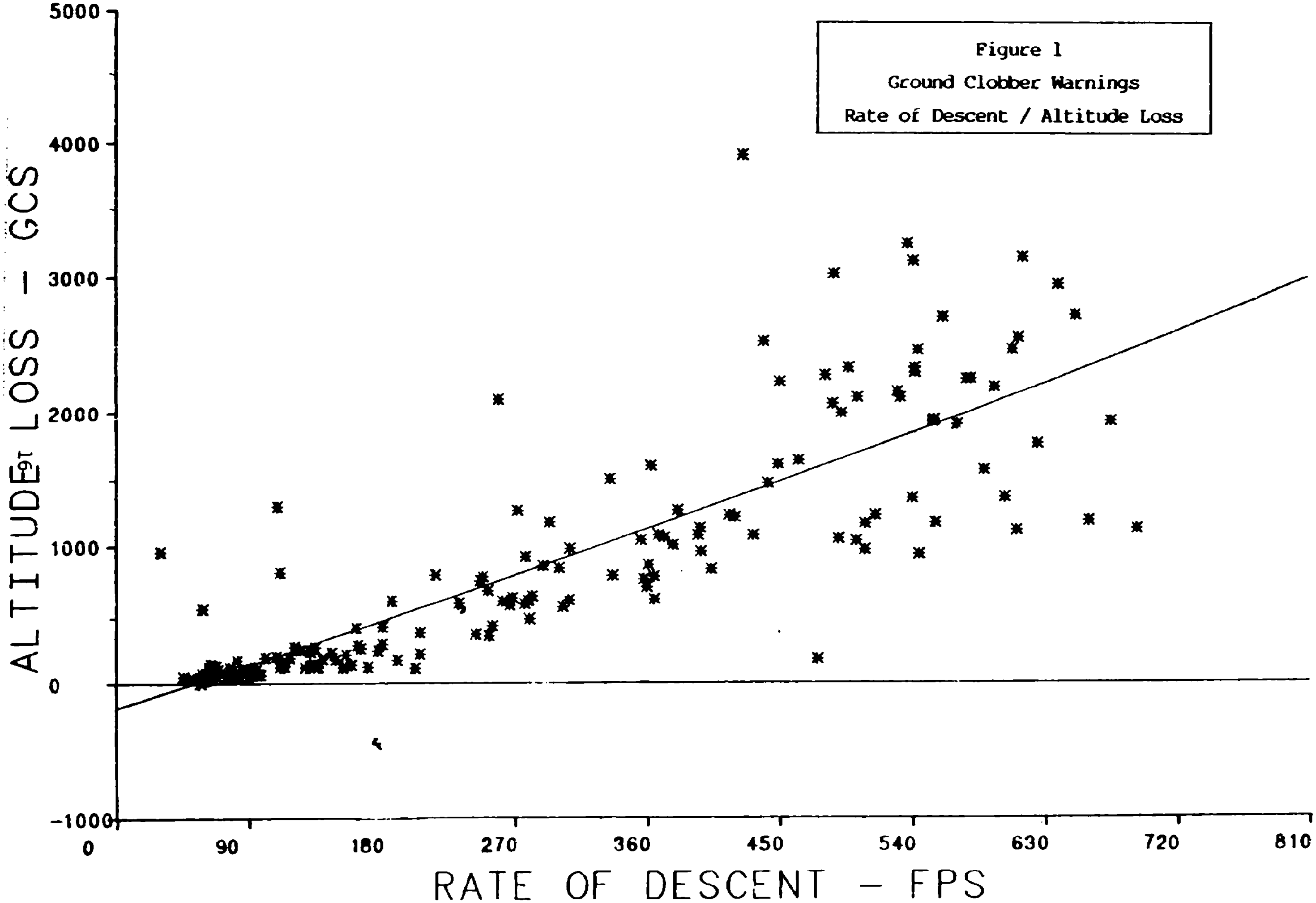


Figure 1
Ground Clobber Warnings
Rate of Descent / Altitude Loss
ALTITUDE LOSS - GCS
5000
4000
3000
2000
1000
0
-1000
0
90
180
270
360
450
540
630
720
810
RATE OF DESCENT - FPS

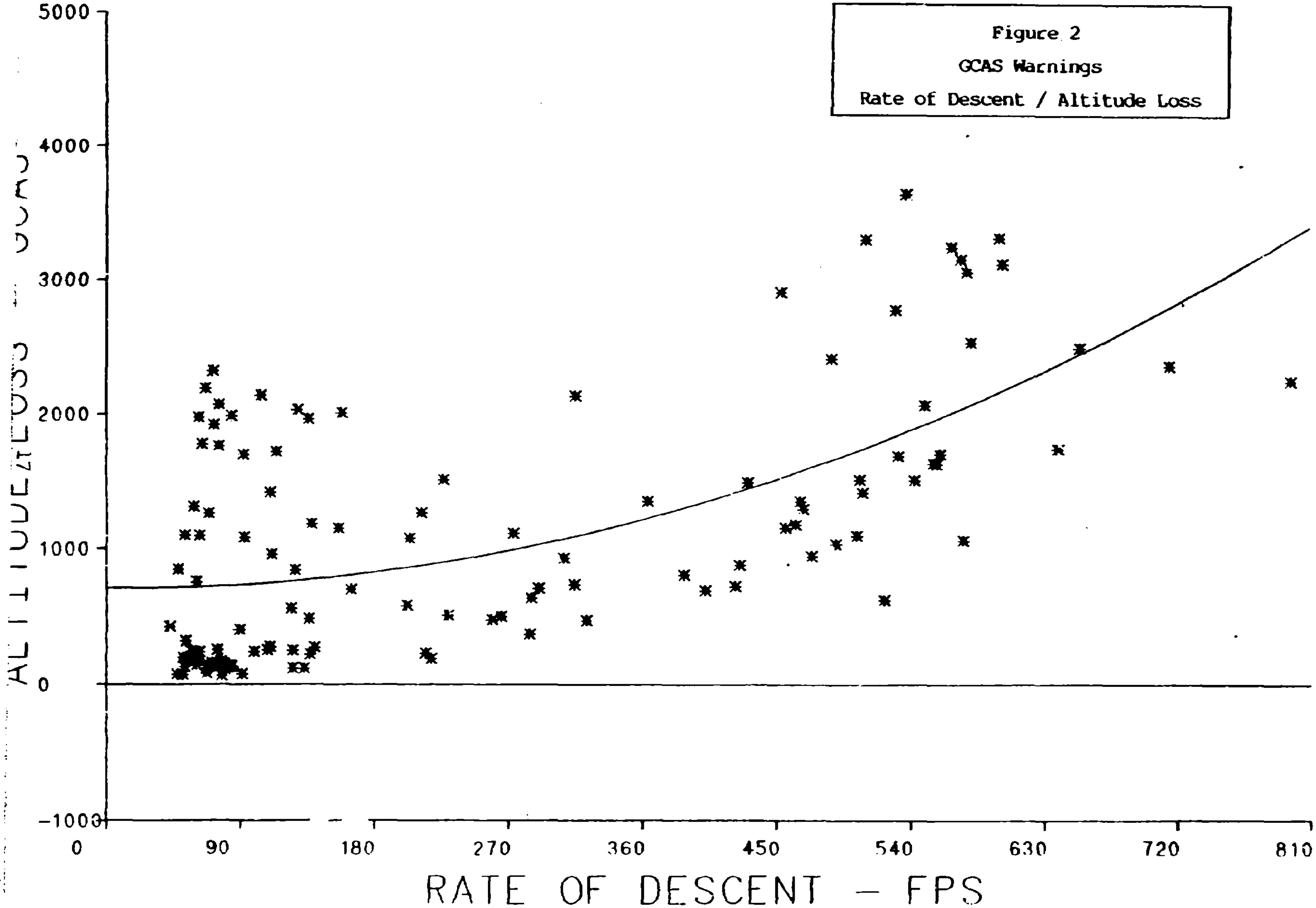


Figure 2
GCAS Warnings
Rate of Descent / Altitude Loss

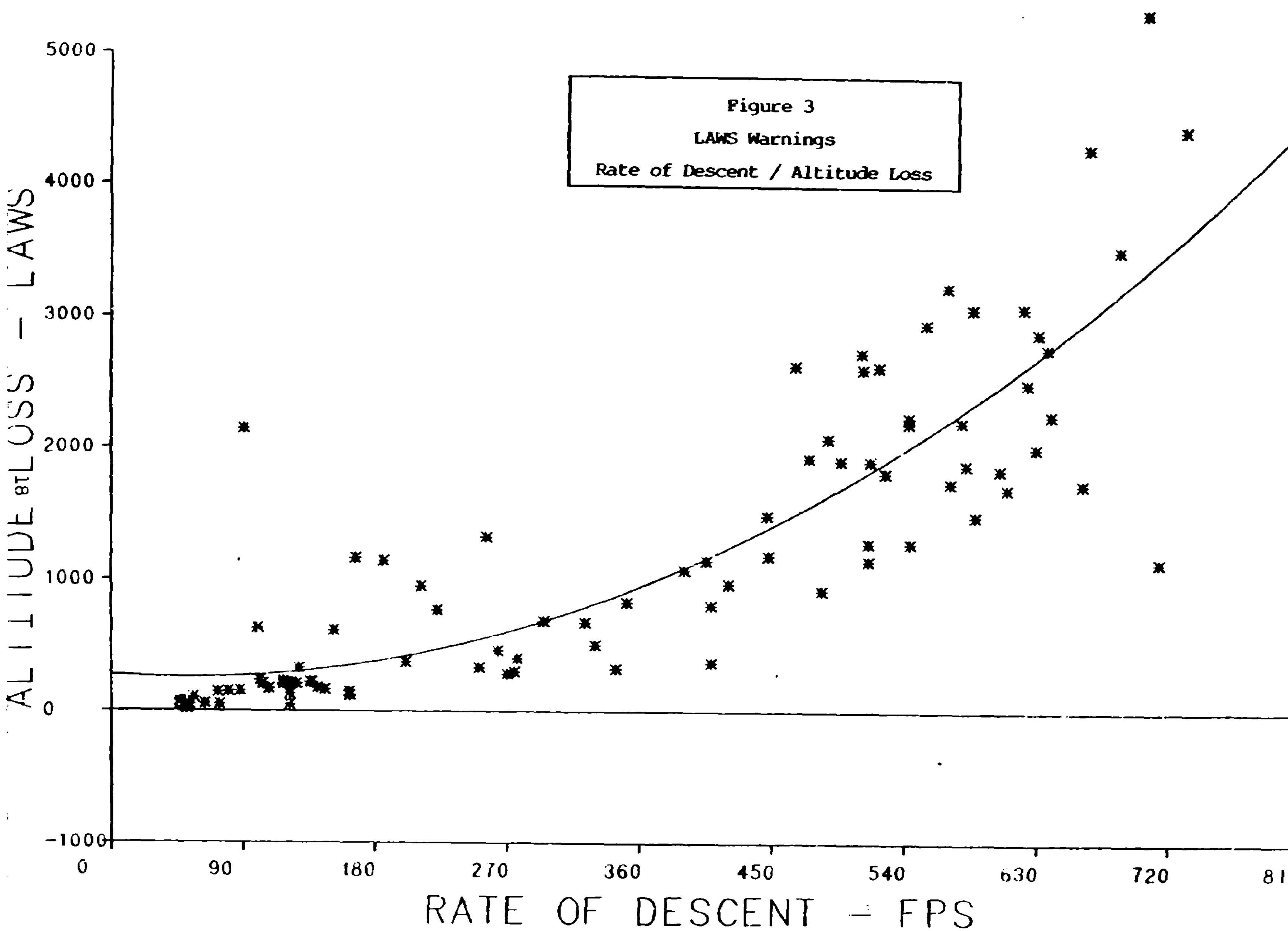


Figure 3

LAWS Warnings

Rate of Descent / Altitude Loss

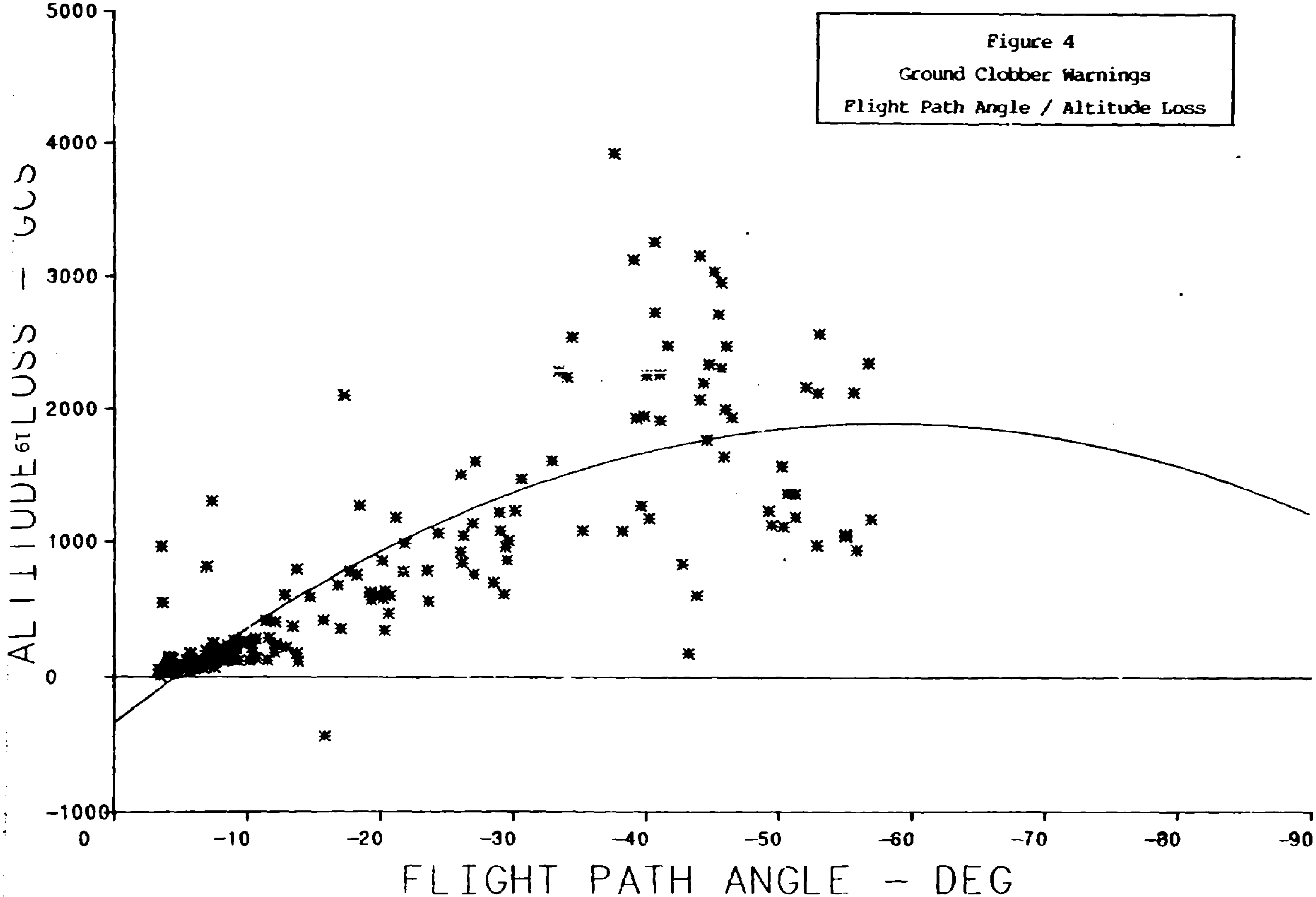


Figure 4
Ground Clobber Warnings
Flight Path Angle / Altitude Loss

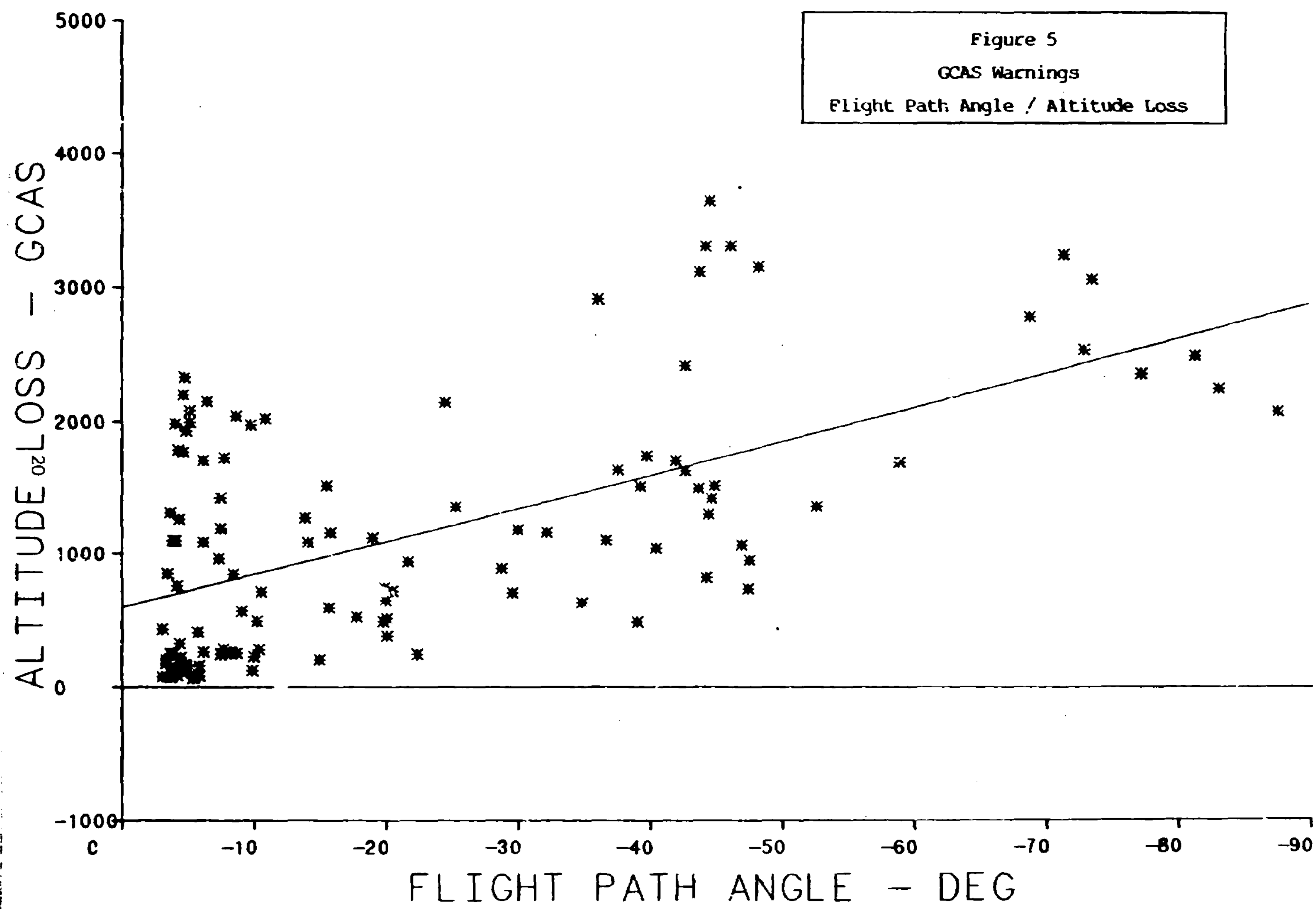


Figure 5
GCAS Warnings
Flight Path Angle / Altitude Loss
5000
4000
3000
2000
1000
0
-1000
ALTITUDE LOSS - GCAS
C
-10
-20
-30
-40
-50
-60
-70
-80
-90
FLIGHT PATH ANGLE - DEG

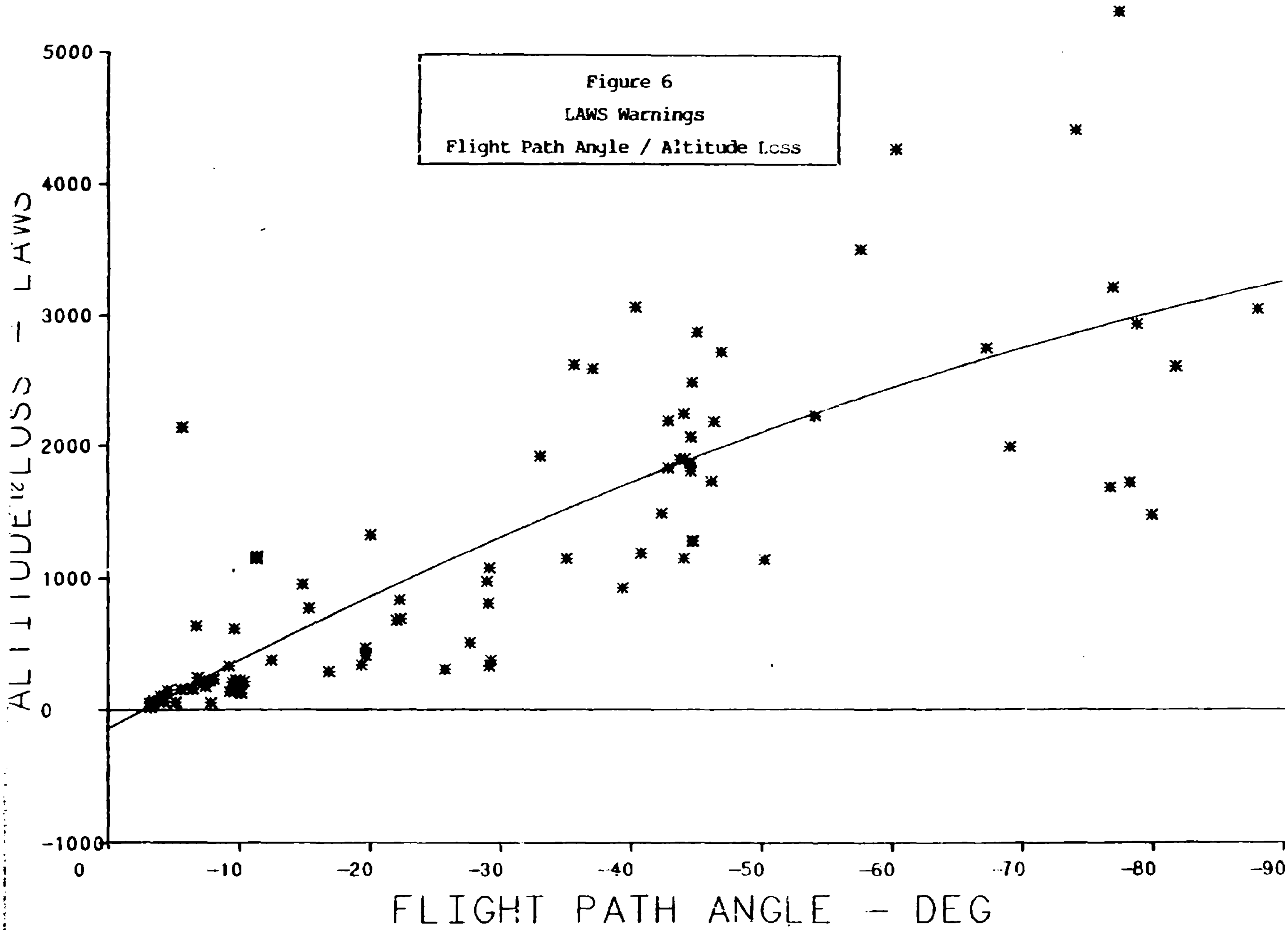


Figure 6
LAWS Warnings
Flight Path Angle / Altitude Loss
ALTITUDE LOSS - LAWS
5000
4000
3000
2000
1000
0
-1000
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
FLIGHT PATH ANGLE - DEG

CRASH DATA

There were 107 total crashes as a result of this simulation study. Table 5 shows a breakdown of the crashes by algorithm and mission.

TABLE 5. CRASH DATA

ALGORITHM	MSN 15	MSN 16	MSN 17	TOTAL
Ground Clobber	6	11	16	33
GCAS	7	8	23	38
LAWS	6	12	18	36
TOTAL	19	31	57	107

The crash data provided no significant differences between the algorithms ($\chi^2_{4,.05} = 0.355$). The differences between crashes with regard to algorithm type can be solely attributed to chance. There was a significant difference between the total number of crashes over the missions, explainable in part by the different mission profiles.

The design of this study allowed for a direct comparison between the active and inactive algorithms over all 107 crashes. In the next section, a comparison will be made to determine how the off-line algorithms might have provided for a successful pull-out. The analysis was based at times on subjective calls, but the author's judgement was conservative at all times. In other words, it had to be obvious; given the airspeed, bank angle, G's, and flight path angle at the time of an off-line warning, that the pilot would have been able to pull out. This evaluation considered that any off-line warnings occurring either after the actual warning or at the same time would have also resulted in a crash. Interpretation was required only when the off-line warnings were prior to the on-line warnings or were the only warnings. Rationale will follow the two off-line algorithm analyses for each of the nine cases (three algorithms over three missions). Following the rationale, a result will be noted, identifying the number of crashes expected if the mission were flown with that algorithm on-line.

<u>Ground Clobber Mission 15</u>: Six crashes resulted with three warnings provided to the pilot prior to impact (Appendix D, part 1, plots 1-6).

LAWS Analysis:	Warnings After	1
	No Warnings Prior to Impact	5

Results: If the mission were run with LAWS, six crashes would have resulted.

GCAS Analysis:	Warnings Before	3
	Warnings at Same Instance	1
	No Warnings Prior to Impact	1
	GCAS Only Warning	1

In the instance where GCAS provided the only warning (plot 2), the pilot would not have had sufficient time and G available to pull out. Of the three instances in which GCAS provided warnings prior to GC, the pilot should have been able to recover at least once (plot 3).

Results: If the mission were run with GCAS, five crashes would have resulted.

Ground Clobber Mission 16: Eleven crashes resulted. Of these eleven, five had warnings provided to the pilot prior to impact (Appendix D, part 2, plots 1-11).

LAWS Analysis:	Warnings Before	4
	Warnings After	1
	No Warnings Prior to Impact	2
	Warned with Other Off-line Algorithm	2
	LAWS Only Warning	2

In the four instances when LAWS warned prior to GC (plots 2, 4, 6, and 11), it appears the pilot would have had sufficient warning to pull out. The two cases when LAWS provided a warning with GCAS (plots 3 and 10) indicate the pilot would have had enough time to avoid crashing. The two cases when LAWS provided the only warning (plots 1 and 7), the pilot would not have had ample time to pull out. In plot 1, the warning was three seconds (sec) prior to impact, but given the FPA and bank angle at the warning instance, it would appear to be insufficient.

Result: If the mission were run with LAWS, five crashes would have resulted.

GCAS Analysis:	Warnings Before	4
	Warnings at Same Instance	1
	No Warnings Prior to Impact	2
	GCAS Only Warning	2
	Warned with Other Off-Line Algorithm	2

In the four instances when GCAS warned prior to GC (plots 2, 4, 6, and 11), the pilot appears to have been able to pull out in all cases. The two instances when GCAS was the only algorithm providing a warning (plots 5 and 9), it also appears the pilot could have avoided a crash. The two cases when GCAS warned off-line with LAWS (plots 3 and 10), it appears the pilot could have pulled out.

<u>Result</u>: If the mission were run with GCAS, three crashes would have resulted.

<u>Ground Clobber Mission 17</u>: Sixteen crashes resulted. Of these sixteen crashes, six warnings were provided to the pilot prior to impact (Appendix D, part 3, plots 1-16).

<u>LAWS Analysis</u>:

Warnings Before	1
No Warnings Prior to Impact	12
Warned With Other Off-line Algorithm	2
LAWS Only Warning	1

In the one instance when LAWS warned prior to GC (plot 8), it appears the pilot would have been able to pull out. In the two cases when LAWS provided a warning when the on-line algorithm did not (plots 13 and 14), the pilot could have pulled out in one case (plot 14), but not in the other. LAWS provided the only warning (plot 6) apparently in sufficient time for the pilot to recover.

<u>Result</u>: If the mission were run with LAWS, 13 crashes would have resulted.

<u>GCAS Analysis</u>:

Warnings Before	3
Warnings After	2
No Warnings Prior to Impact	5
GCAS Only Warning	4
Warned With Other Off-line Algorithm	2

In the three instances when GCAS warned prior to GC (plots 7, 12, and 16), the pilot would have had sufficient time in two cases (plots 7 and 16) to avoid crashing. Of the four cases when GCAS provided the only warning (plots 1, 2, 4, and 15), it appears the pilot would not have had sufficient warning to recover in any instance. Of the two cases when GCAS warned with LAWS (other off-line algorithm), the pilot could have pulled out in one case.

<u>Result</u>: If the mission were flown with GCAS, 13 crashes would have resulted.

GCAS Mission 15: Seven crashes resulted. Of these seven, four warnings were provided to the pilot prior to impact (Appendix D, part 4, plots 1-7).

LAWS Analysis:

Warnings Before	1
Warnings After	1
No Warnings Prior to Impact	4
LAWS Only Warning	1

In the two instances when LAWS warned prior to GCAS, the pilot would have had sufficient warning to pull out. In the case when LAWS provided the only warning prior to impact (plot 3), the warning would have been in sufficient time to pull out.

Result: If the mission had been flown with LAWS, five crashes would have resulted.

GC Analysis:

Warnings Before	1
Warnings After	1
No Warnings Prior to Impact	5

The one GC warning that occurred before the GCAS warning (plot 1) would have enabeled the pilot to pull out.

Result: If the mission had been flown with GC, six crashes would have resulted.

GCAS Mission 16: Eight crashes in which seven warnings were provided to the pilot prior to impact (Appendix D, part 5, plots 1-8).

LAWS Analysis:

Warnings Before	2
Warnings After	3
No Warnings Prior to Impact	2
LAWS Only Warning	1

In the two instances when LAWS provided a warning before GCAS (plots 1 and 14), it appears the pilot would have had enough time to recover in one case (plot 1). In the instance when LAWS provided the only warning prior to impact (plot 3), the pilot could have recovered.

Result: If the mission had been flown with LAWS, six crashes would have resulted.

GC Analysis: Warnings Before 6
No Warnings Prior to Impact 2

In the six cases when GC warned prior to GCAS (plots 1, 2, and 4-7), it appears the pilot would have had sufficient time to pull out in three cases (plots 1, 4, and 6). In one other instance, a recovery may have been possible, but would have been close given the flight path angle and low air speed.

Result: If the mission had been flown with GC, five crashes would have resulted.

GCAS Mission 17: Twenty three crashes resulted, in which fifteen warnings were provided to the pilot prior to impact (Appendix D, part 6, plots 1-23).

LAWS Analysis: Warnings Before 2
Warnings After 2
No Warnings Prior to Impact 19

In the two cases when LAWS provided a warning prior to GCAS (plots 10 and 21), the pilot would have had enough time to pull out in one instance (plot 10), and insufficient time in the other.

Result: If the mission had been flown with LAWS, 22 crashes would have been recorded.

GC Analysis: Warnings Before 6
Warnings After 2
Warnings at the Same Instance 4
No Warnings Prior to Impact 11

Of the six cases when GC warned the pilot before GCAS (plots 7, 10, 11, 14, 15, and 19), the pilot would have been able to pull out in one case (plot 11). The other five cases would not have warned the pilot in sufficient time.

Result: If the mission had been flown with GC, 22 crashes would have been recorded.

LAWS Mission 15: Six crashes resulted, with no warnings to the pilot prior to impact (Appendix D, part 7, plots 1-6).

GCAS Analysis: Only Warning 3
Warned with Other Off-line Algorithm 3

In the three cases when GCAS provided the only warning (plots 1,3,5), the pilot would have been warned in sufficient time to pull out in only one case (plot 3). In the three cases when GCAS warned with the GC algorithm, both off-line, the pilot may have avoided a crash in one instance (plot 6). In this case, the GCAS warning is in response to rising terrain which the pilot may have considered a nuisance. It is unclear whether the pilot would have changed the aggressive bunt down the backside of the ridge. If he did not, he still would have crashed.

Result: If the mission had been flown with GCAS, five crashes would have been recorded.

GC Analysis: No Warnings Prior to Impact 3
Warned with Other Off-line Algorithm 3

Plots 1, 3, and 5 show GC provided no warning prior to impact. Plots 2, 4, and 6 show GC did provide off-line warnings to the pilot that would not have provided warning in sufficient time to avoid crashing. In plot 6 the warning was approximately 1.5 seconds prior to impact.

Result: If the mission had been flown with GC, six crashes would have been recorded.

LAWS Mission 16: Twelve crashes resulted, with seven warnings to the pilot prior to impact (Appendix D, part 8, plots 1-12).

GCAS Analysis: Warnings Before 7
No Warnings Prior to Impact 1
Warned with Other Off-line Algorithm 2
GCAS Only Warning 2

The seven cases where GCAS provided a warning before LAWS are shown in plots 2, 4, 5, and 8-11. If the pilot were responding to a GCAS warning, it appears the crashes in plots 2, 8, 9, 10, and 11 could have been avoided. The crash represented by plot 4 does not indicate the pilot responded with as great a sense of urgency as required. For this reason, the GCAS warning 1.2 sec earlier would probably have resulted in a crash. The crash depicted in plot 5 indicates the earlier GCAS warning (approx 0.4 sec earlier), was insufficient to change its outcome. Plots 3 and 6 depict the cases when GCAS provided the only warnings prior to impact. It appears in both cases the pilot would have been warned in sufficient time to pull out. In the two cases when GCAS provided a warning with the other off-line algorithm, it again appears sufficient warning would have been given to allow a recovery (Plot 7 with 5 sec and plot 12 with a 3.25 sec

warning prior to impact).

Result: If the mission were flown with GCAS, three crashes would have been recorded.

GC Analysis:		
	Warnings Before	5
	Warnings After	1
	No Warnings Prior to Impact	4
	Warned with Other Off-line Algorithm	2

The five cases when the GC warning came on before the LAWS warning (plots 4, 5, 8, 9, and 11), would have probably resulted in fewer crashes. The pilot would have received a warning 2.5 sec earlier in plot 4, about 3.5 sec in plot 5, 3.25 sec in plot 8, 3.5 sec in plot 9, and 2.5 sec in plot 11. It appears the pilot could have pulled out in every case except that depicted in plot 4. The extension of the flight path in plot 4 after the pilot received the LAWS warning, back to the point where GC came on, indicates the pilot would have crashed. In plots 7 and 12, GC provided a warning with the other off-line algorithm. In both of these cases, it appears the pilot would not have had time to recover. Both warnings were approximately 1.5 - 2.0 sec prior to impact.

Results: If the mission were flown with GC, eight crashes would have been recorded.

LAWS Mission 17: Eighteen crashes resulted. Of these eighteen, five warnings were provided to the pilot prior to impact (Appendix D, part 9, plots 1-18).

GCAS Analysis:		
	Warnings Before	3
	Warnings After	2
	No Warnings Prior to Impact	2
	Warned with Other Off-line Algorithm	7
	GCAS Only Warning	3
	Warned at Same Instance	1

The three cases when GCAS provided warnings before LAWS are shown in plots 8, 9, and 18. In plot 8, the pilot may have considered the GCAS alarm a nuisance and may not have responded by reducing the aggressiveness of his bunt down the backside of the ridge. It is therefore not clear if the crash would have been avoided. In plot 9, the GCAS warning preceded the LAWS warning by 2 sec. This would have been insufficient, given the flight path, to prevent the crash. In plot 18, the GCAS warning was less than 2 sec prior to LAWS and would not have provided time to pull out. In the seven cases when GCAS provided a warning along with the other off-line algorithm (plots 1, 3, 5, 7, 10, 14, and 15), it appears the pilot could have avoided a mishap in one case if he responded to a GCAS warning. In plot 15, the pilot was flying over rough terrain toward a ridge. GCAS

provided a warning 10 sec prior to impact, although not necessarily responding to the danger of the ridge impacted. A crash nonetheless could have been avoided if the pilot had reacted to the GCAS alarm. However, it is unclear if this would have been the case. The three cases GCAS provided the only alarm (plots 4, 13, and 17), crashes could have been avoided in two cases. In plot 4, GCAS provided a warning 10 sec prior to impact. Although the GCAS warning could be considered somewhat premature, if the pilot had responded, he would have avoided the ridge-clip. In plot 13, the GCAS warning was 2 sec prior to impact,. and given the flight parameters, it appears a crash could have been avoided.

Result: If the mission had been flown with GCAS, 15 crashes would have been recorded.

GC Analysis:

Warnings Before	2
Warnings After	2
Warnings at Same Instance	1
GC Only Warning	1
Warned with Other Off-line Algorithm	7
No Warnings Prior to Impact	5

The two cases when GCAS provided warnings before LAWS are shown in plots 8 and 18. In plot 8, the pilot may have considered the GCAS alarm a nuisance and may not have responded by reducing the aggressiveness of his bunt down the backside of the ridge. It is therefore not clear if the crash could have been avoided. In plot 8, the GC alarm preceded LAWS by 2 sec. This would appear to be insufficient to avoid impact. The case when GC provided the only warning is shown in plot 16. This warning proceeded impact by less than 1 sec, providing insufficient time for recovery. The seven cases when GC provided an off-line warning with GCAS are shown in plots 1, 3, 5, 7, 10, 14, and 15. In plot 3, GC provided a warning 10 sec prior to impact. If the pilot reacted to the pull-up warning and did not consider it a nuisance, the crash would most likely have been avoided. It is clear in the other cases that the GC warning would have been insufficient to avoid crashing.

Result: If the mission were flown with GC, 17 crashes would have been recorded.

The resultant on-line/off-line crash data are shown in Table 6.

Table 6. ON-LINE/OFF-LINE DATA

ALGORITHM	MSN 15	MSN 16	MSN 17	TOTAL
Ground Clobber	18	24	55	97
GCAS	17	14	51	82
LAWS	17	23	53	93
TOTAL	52	61	158	271

The crash data again reveals no significant differences between the algorithms, regardless of the increase in data points, $\chi^2_{wr.05} = 1.047$). The large number of crashes associated with Mission 17, in comparison with Missions 15 and 16, can be explained by the more aggressive maneuvers required for this mission. It would be difficult to accurately project how the modified GCAS algorithm would have performed. However, since the changes were aimed at reducing niusance warnings (essentially providing warnings closer to the ground), one would speculate the number of crashes would be greater when compared to the crash performance of the unmodified GCAS algorithm.

PERFORMANCE IN SPECIFIED ENVIRONMENTS

The crash data does not highlight one algorithm as being clearly superior to the others. The crash plots will now be divided into different flight profiles to determine if one algorithm is superior to the others in a specific environment. The next section will examine this potential over three profiles: flat earth, descents into rising terrain, and level flight into rising terrain.

FLAT EARTH

There were 21 plots identified as descents into flat terrain. The GCAS algorithm provided a warning in each instance (21/21), with an average warning of 5.24 sec prior to impact. The GC algorithm provided warnings in 17 instances (17/21), with an average warning of 5.81 sec. The LAWS algorithm warned in 16 instances (16/21), with an average warning of 4.19 sec.

It is important to note that none of the 21 plots used to arrive at the data were affected by inputs from the experimenter's control station. The pilot was acting at his own control during all 21 cases. In addition, the warning frequency cannot be tied to either valid or niusance warnings. Warning frequency does however, provide input on the breadth of coverage in a specific environment. The data indicate GCAS provides warnings under more conditions than GC or LAWS in the flat earth environment. The GCAS and GC algorithms on the average provided 5.24 sec and 5.81 sec warnings respectively, considerably more than the 4.19 sec LAWS average warning. This 1.0 - 1.5 sec average warning time discrepency can be attributed in part to the lack of a G - limit in the LAWS algorithm. Crash frequency can be assessed in this environment and is shown in Table 7.

TABLE 7. DIVING INTO FLAT TERRAIN

ALGORITHM	AVERAGE WARNING TIME	WARNING FREQ	CRASH FREQ
GROUND CLOBBER	5.81s	17/21	9/12
GCAS	5.24s	21/21	10/12
LAWS	4.19s	16/21	14/21

The data indicate a non-significant difference between the algorithms with regard to crash frequency, $\chi^2_{\alpha, .05} = 1.27$. The data nonetheless is indicative of the philosophical differences between the algorithms.

DESCENTS INTO RISING TERRAIN

There were 12 plots identified as descents into rising terrain. A minimum average slope of six degrees for the three seconds prior to impact was the criterion used to define rising terrain. The GCAS algorithm provided a warning in 9 instances (9/12), with an average warning of 1.1 sec. The GC algorithm provided warnings in 5 instances (5/12), with an average warning of 0.76 sec. The LAWS algorithm warned in no cases (0/12).

The data indicate GCAS provides warnings significantly more often, $\chi^2_{\alpha, .05} = 8.71$ than the other algorithms in this environment. The crash

plots, however, indicate the additional warnings provided little protection against crashes as indicated in Table 8.

TABLE 8. DIVING INTO RISING TERRAIN

ALGORITHM	AVERAGE WARNING TIME	WARNING FREQ	CRASH FREQ
GROUND CLOBBER	0.76s	5/12	12/12
GCAS	1.10s	9/12	11/12
LAWS	0.00s	0/12	12/12

The data in this environment indicate none of the three algorithms provide adequate protection against descents into rising terrain.

LEVEL FLIGHT INTO RISING TERRAIN

There were 24 plots identified as level flight into rising terrain. A minimum average slope of six degrees for the three seconds prior to impact was the criterion used to define rising terrain. Warnings were provided by GCAS in 12 instances (12/24), with an average warning time of 0.28 sec. The GC algorithm provided five warnings (5/24), with an average warning time of 0.27 sec. LAWS provided no warnings in the 24 cases. The LAWS minimum design altitude of 90' should have provided warnings when 90' was penetrated. As previoully discussed, this would have provided insufficient warning to avoid crashing. The data indicate none of the algorithms provide protection from level flight ($\pm$5) into rising terrain (Table 9).

TABLE 9. LEVEL FLIGHT INTO RISING TERRAIN

ALGORITHM	AVERAGE WARNING TIME	WARNING FREQ	CRASH FREQ
GROUND CLOBBER	0.28s	5/24	24/24
GCAS	0.28s	12/24	24/24
LAWS	0.00s	0/24	24/24

GCAS provides significantly more warnings in this environment, $\chi^2_{\alpha=.05} = 12.82$, although providing minimal additional protection.

SUBJECTIVE DATA

Subsequent to each flight and at the end of the evaluation, pilots were asked to rate each warning system on a variety of Pilot Vehicle Interfaces (PVI) and systems operations areas. The tabulated results of questionnaire data are shown in Appendix C.

Asked to rate timeliness of the warning systems on a five point scale, a majority of the pilots rated the systems "Just Right". Ratings were: Ground Clobber 53%, GCAS 57%, and LAWS 62.5%. The next most often rated description for all systems was "Too Early", with Ground Clobber 27%, GCAS 25%, and LAWS 12.5%.

When asked how often they had nuisance warnings on a five point scale, the majority chose "Seldom" most often, for ground clobber and GCAS, with 33.3% and 43.7% respectively. "Never" scored highest for LAWS with 62.5%.

Most pilots rated the attention getting characteristics of the system highly. Asked if the warnings got their attention, the rating selected most often was "Yes, all the time", with 73% for Ground Clobber, 87.5% for GCAS and 79.2% for LAWS. "Most of the time" was the only other selection for all systems.

VI. DISCUSSION

This study did not conclusively identify one algorithm as being clearly superior to the others. All three, however, differ in obvious ways that will now be discussed.

WARNING SYSTEM CONCEPT

If either one of the three competing systems or even a combination of the best features of all three are determined to be necessary in fighter aircraft, pilots must be cautioned that the system will not protect against CFIT in all conditions.

While all these algorithms are relatively straightforward in terms of calculations to change flight path, they differ in approaches to limit the number of unnecessary or "nuisance" warnings. Essentially, they all try to anticipate pilot intentions in a variety of conditions. For example, the three algorithms inhibit, or by some other means, eliminate most of the "look forward" aspects of the calculation to eliminate, or minimize unnecessary warnings during ridge or hill crossings in near level flight. As a consequence, there is minimal warning or protection against flight into rising terrain when the aircraft path angle is less than five degrees for GCAS and GC, and less than three degrees for LAWS. Under these conditions the LAWS provides a warning at 90 ft. above the terrain, and the GCAS at the set ALOW setting.

PULLUP ANTICIPATION CUE

The General Dynamics Ground Clobber algorithm is the only one of three evaluated that provides an alert cue to advise the pilot of an impending "PULL-UP" warning. This cue is designed to appear 10 seconds prior to the PULL-UP. Actually it can appear much less than 10 seconds prior to a warning in Dynamic low level maneuvering.

The anticipation symbol is the same one used for pull-up anticipation in air-to-ground bombing models and also as an arming delay cue. In some cases the symbol could appear twice during a delivery, first as an arming delay cue and then, after weapon release, as a pull-up cue. Careful consideration should be given to assigning a third function to the same symbol. This puts the pilot in the position of trying to determine which of three advisory functions caused the cue to appear. The AFTI F-16 has an anticipation function that uses two halves of the Break "X" cue that appear separated at the anticipation cue and move laterally to form the Break "X" at the pullup warning. This may be an option.

Another potential problem in this mechanization was that the anticipation cue had to be seen to provide any useful information to the pilot. As such, if he was preoccupied with cockpit systems operation, attempting to locate another flight member, or checking six, the cue was useless. If appearance of the cue was accompanied by a tone or some other audible alert, its utility could be expanded through the rest of the algorithm's useful flight envelope.

SELECTABLE GROUND CLEARANCE SETTING

The GCAS was the only one of the three algorithms that included a pilot selectable minimum altitude. (LAWS is set at 90 feet, GC at 50 feet). For this evaluation, the GCAS ALOW setting was constant at 90 feet to provide consistent and comparable data, however, the added flexability is considered a strength.

Altitude warning systems such as those used in this evaluation are primarily for peacetime training environments. It is highly unlikely that a pilot would have emitters such as the radar altimeter operating in a threat environment; hence, no warning system. However, since different categories of tactical pilots have different minimums in the low level training environment, the ability to select more, or less, protection in terms of warning height can be a distinct advantage. One thing that must be considered in an F-16 integration is the establishment of some minimum default value for the warning system. In this test, the ALOW feature in the F-16 cockpit was used to establish the GCAS clearance buffer. Currently, ALOW defaults to zero with aircraft electrical power cycles; this would have to be changed to some agreed upon value such as 100 feet with the same pilot selectable option to set the minimum higher or lower at his discretion.

EARLY WARNINGS

One potential problem noted with the Ground Clobber and earlier GCAS algorithms were pilot reports of early warnings during dive recoveries. This was especially true at the higher dive angles experienced during the weapons delivery maneuvers. As long as dive angles were limited to 20-25 degrees, pilots were able to complete the deliveries without a pull-up warning. When dive angles increased to 30 degrees or more, warnings frequently occurred up to 1000 feet or more above the briefed release altitude, while pilots were making flight path corrections on the delivery runs. These were normally reported as early warnings and, because they were obviously early, pilots merely flew through the warning and completed the delivery. The obvious problem here, of course, is that with more experience with the system, pilots will ignore warnings when they think they are in a situation that might lead to early activation.

It was somewhat surprising that evaluation pilots were as tolerant as they were with what has been referred to as "nuisance warnings". Probably the primary reason for this is that they understood the limitations of a look-down radar altimeter as a device to "see" what is ahead of the aircraft. During the evaluation flights and in de-briefing, they seemed less tolerant of the lack of warnings in near level flight, when flying into rising terrain, and in steep bank (hard) turns exceeding the roll limits of the CARA.

RECOMMENDATIONS FOR FUTURE STUDIES

The initial focus of this report was to test the Ground Clobber Algorithm over a variety of flight scenarios. The study was therefore designed to test the algorithm over different terrain profiles with the man-in-the-loop. This design introduced a fair amount of subject variability and made it difficult to clearly ascertain if one of the three algorithms tested was superior to the others. A study to test the differences or similarities and advantages or disadvantages of each algorithm can be more easily assessed in a controlled laboratory environment. Flying the algorithms against specific profiles with only one subject pilot providing input would provide clean, comparative data. The profiles may include varying degrees of dive into rising terrain and level terrain. The profiles can be further characterized by varying bank angle and air speed.

CURRENT ALGORITHM CONFIGURATIONS

The algorithms evaluated in this study were current through November, 1986. (A more current version of GCAS dated January, 1987 was also addressed in the report). Because these algorithms are continually subjected to modifications, the reader is provided information to attain the most up-to-date algorithm configuration.

GCAS .... Dave Buyer
AFLC LOC/SDVA
AV 787-4210
Comm 257-4210

GC .... Capt Bruce Pete
ASD/YPEF
AV 785-6605
Comm 255-6605

LAWS .... Ms. Diane Shah
ASD/ENFTC
AV 785-5563
Comm 255-5563

VII. CONCLUSIONS

1. All three systems tested will provide warnings in sufficient time to recover in some CFIT situations.

2. All three systems provide little or no protection in near level flight into rising terrain conditions.

3. Similarly, protection against CFIT in shallow descents/climbs is marginal.

4. None of the systems tested provide a complete solution to the CFIT problem.

5. For all practical purposes, all three systems are of little or no use in aircraft attitudes outside CARA limits of plus or minus 45 degrees of pitch and plus or minus 60 degrees of roll.

6. Ground Clobber warning and recovery altitudes are significantly higher than either LAWS or the latest GCAS.

7. Pilots generally liked the Ground Clobber prediction cue concept, however, the symbol should receive further evaluation, and an audible tone should be considered. Additional guidance for tone usage can be found in MIL-STD-1800, Human Engineering Performance Requirements for Systems (4.6 Audio Signals).

8. The selectable warning altitude feature in the GCAS is a plus, especially in a peacetime/training environment where the system(s) will be available.

9. Under most conditions, recoveries from LAWS warnings will lead to exceeding F-16 stores "G" limits.

10. Of the three systems, only GCAS provides protection in over-the-top maneuvers, and it will do this only under limited entry conditions.

APPENDIX A

GC ALGORITHM MECHANIZATION

The Ground Collision algorithm used in this evaluation is commonly referred to as the Operational Capabilities Upgrade (OCU) version. Another Enhanced Ground Clobber modification of the algorithm was also flown by each participating pilot on one mission during the evaluation. Both algorithms will be discussed in the following paragraphs.

OCU Ground Clobber

The basic OCU algorithm is an extension of the original F-16 A/B Ground Clobber system that uses either Air to Ground Range (AGR) data or system altitude/target altitude values. The primary source of data for the OCU algorithm is the CARA system with backup capabilities similar to the A/B system in the event of loss of valid CARA data.

The algorithm continuously compares aircraft height above the ground with the altitude required for dive recovery. It predicts altitude loss during dive recovery as a sum of the following:

a. Altitude loss due to pilot response time.
b. Altitude loss during roll recovery.
c. Altitude loss during a 4-G pullup.

A 50 foot buffer is resident in the system so that if the aircraft is flown exactly in accordance with the algorithm assumptions, recoveries will be completed at 50 feet AGL + 10% of the altitude lost during the pullup. Figure 7 shows basic system operation.

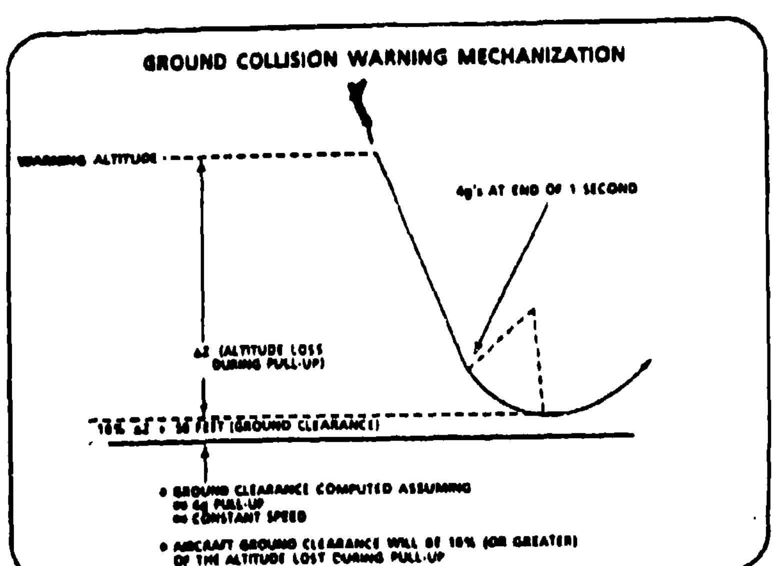


Figure 7, OCU Ground Clobber Mechanization

The following values are used in calculating altitude loss in the recovery procedure.

a. Pilot response time. The algorithm assumes that the pilot will react to a warning in 1.0 second. The value is consistent with recorded pilot response times in the 1986 GCAS evaluation: (0.8 sec).

b. Altitude loss during roll recovery. The time value for roll recovery varies with bank angle as shown in Figure 8. Note that at bank angles of less than 30 degrees, no time is allowed for rolling to wings level. At bank angles in excess of 30 degrees, time allowed varies linearly to a maximum of 3.0 seconds if the aircraft is inverted.

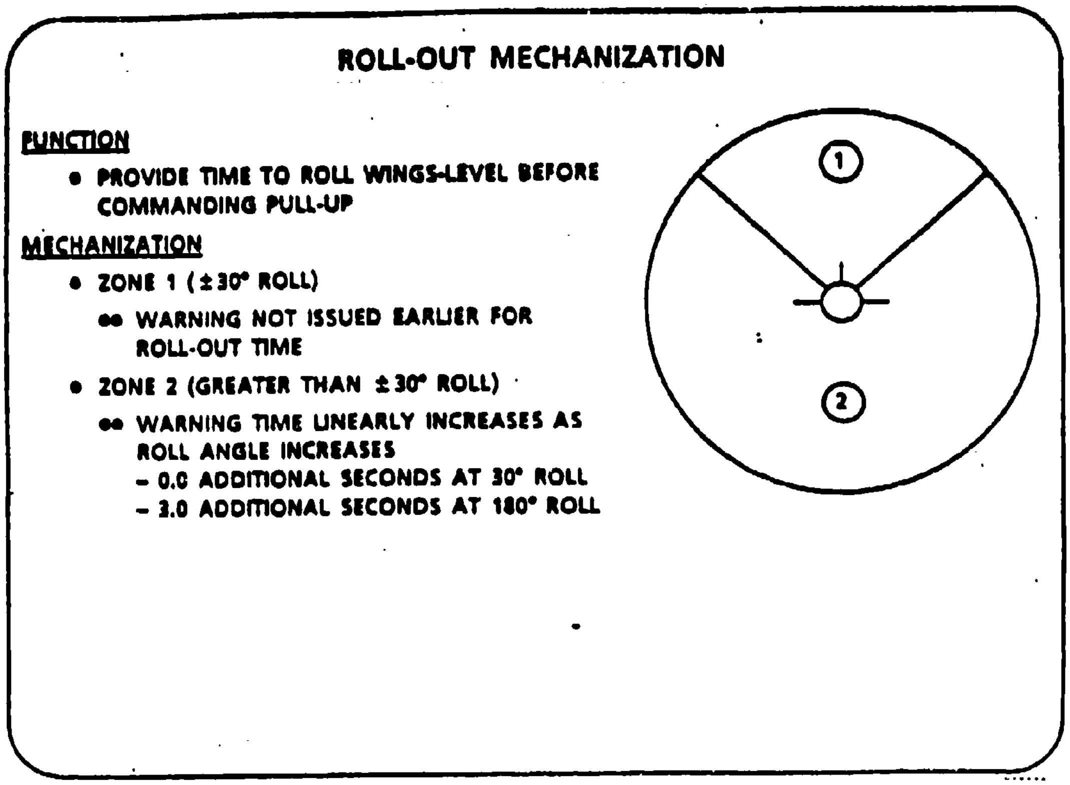


Figure 8, Roll-out Mechanization

c. Altitude loss during a 4-G pullup. One second is added to the altitude loss calculations to account for the time it takes to transition from 1 to 4 G flight.

Additional buffers are included in the system to handle operation in the low speed regime where 4 Gs are not available. The mechanization breaks operations into three ranges; less than 330 knots where the buffer is increased to 15 percent of projected altitude loss, 330-380 knots where it decreases linearly from 15 to 10%, and speeds above 380 knots where it is held constant at 10%.

The combined effects of the timing factors and buffers described above are realistic only if the pilot accomplishes the recovery in a

step-by-step manner. If, on the other hand, conditions for a warning are met during a routine rolling recovery maneuver, pilot response time is essentially zero, roll to wings level time is negligible, and time to 4 Gs may be zero. In this situation the recovery will be completed at an abnormally high altitude and the pilot will report a high or earlier than desired warning.

The algorithm is designed primarily as a dive recovery system. In fact early Ground Clobber mechanization was optimized for a 30 degree dive recovery. As a consequence, there is no real protection against level flight into rising terrain.

The Ground Clobber system assumes a flat earth in that it uses real time CARA inputs without calculating or projecting terrain slope. There is also an inhibit in the system that reduces times for altitude loss due to pilot response time, roll recovery and attaining 4 Gs AGL when he flies toward rising terrain; or when climb angle is less than +5 degrees of level flight. As a consequence, the pilot receives a warning at 50' AGL when he descends toward level terrain, or when climb angle is less +5 degrees and he encounters terrain rising at a greater angle. More often than not, this last minute warning comes too late to even initiate a pull-up to avoid the terrain.

GCAS ALGORITHM MECHANIZATION

The GCAS algorithm was analyzed by CSDF in order to determine the validity of warnings in various flight conditions. For the purpose of this evaluation, an invalid warning is one which occurs too early (a "nuisance" warning), or one which occurs too late for a safe recovery. The algorithm is briefly explained here in order to provide a background for the analysis. Cubic's algorithm continuously compares the aircraft's present height above the ground with the altitude required for dive recovery. The algorithm predicts altitude loss during dive recovery as a sum of the following:

a. Altitude loss due to terrain rise during the pull-up.

b. Altitude loss due to pilot response time.

c. Altitude loss during roll recovery.

d. Altitude loss during a 5-G pull-up.

Figure 9 illustrates this piecewise calculation of altitude loss.

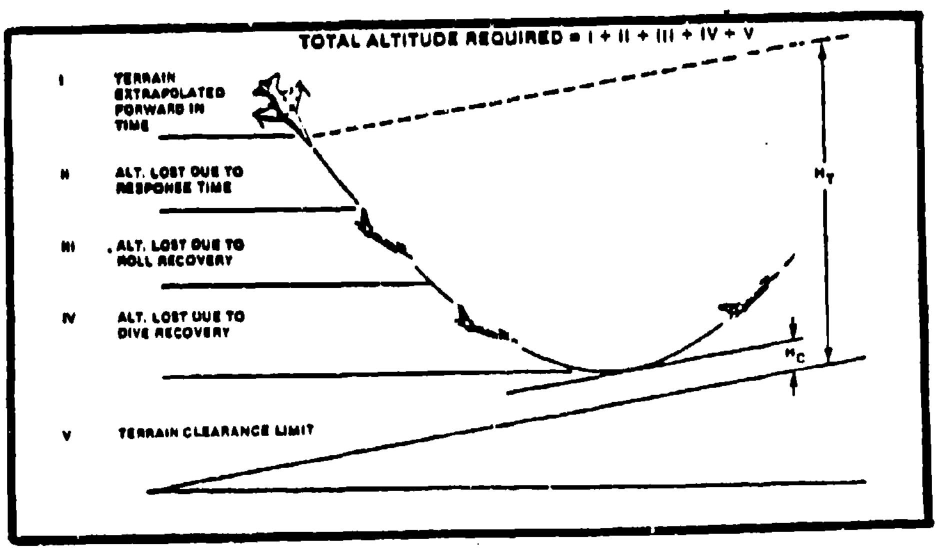


Figure 9. Piecewise Calculation of Altitude Loss

The following paragraphs describe each portion of the altitude loss calculation in detail. Reasons for early or late warnings are also discussed.

a. Altitude loss-pilot response

The initial portion of the altitude loss is fairly simple to compute. During the period of time before the pilot has made any response to a warning, the aircraft is projected to continue its present vertical trajectory. The current vertical velocity is multiplied by a computed response time (T_{resp}) to calculate altitude that would be lost from warning to initial stick input.

b. Altitude Loss During Roll Recovery

The GCAS algorithm predicts the altitude that will be lost while the pilot rolls wings level. This calculation is based on the assumption that the pilot will not begin his dive recovery until he has brought his wings nearly level. The calculation is made in the following manner:

(1) The time for roll recovery is calculated.

$$T_{rr} = \frac{|\phi| - 20^\circ}{\dot{\phi}_{pred}}$$

Where ϕ = roll angle

$\dot{\phi}_{pred}$ = predicted roll rate

= 70 °/Sec for 20 ° < ϕ < 85 °

56 °/Sec for 85 ° < ϕ <145 °

90 °/Sec for 145 °< ϕ <180 °

(2) The vertical velocity is extrapolated

$$V_{rr} = V_z + A_z \cdot T_{rr}$$

where

V_{rr} = Extrapolated vertical velocity

V_z = Instantaneous (measured) vertical velocity

A_z = Instantaneous (measured) vertical acceleration

(3) The flight path angle is extrapolated:

$$\gamma_{rr} = \tan^{-1}\left[\frac{V_{rr}}{V_x}\right]$$

Where V_x = Instantaneous horizontal velocity

(4) The altitude loss due to roll recovery is calculated.

$$\Delta Z_{rr} = V_z \cdot T_{rr}$$

If the altitude loss is negative (i.e. a climb), the absolute value $|\Delta Z_{rr}|$, is used.

If the extrapolated flight path (γ_{rr}) is greater than zero or

If the absolute value of the roll rate is greater than 80 °/Sec,

then ΔZ_{rr} is set to zero.

c. Altitude Loss During Dive Recovery

The algorithm calculates the altitude loss that would occur during a wings level, constant G dive recovery in the following manner:

(1) The basic equation for a constant G constant true airspeed dive recovery is:

$$\Delta Z_{pu} = \left[\frac{V^2}{g}\right] \ln \left[\frac{n - \cos \gamma_{ext}}{n - 1}\right]$$

Where ΔZ_{pu} = the altitude lost during the pullup

V = aircraft true airspeed (ft/sec)

n = G available (max of 5)

γ_{ext} = extrapolated flight path angle

g = 32.2 ft/sec 2

This equation is based on the assumption that dive recovery is complete when $\gamma = 0°$.

d. Altitude loss due to terrain rise

The algorithm calculates the altitude loss due to ground rise using a filtered estimation of the terrain slope directly below the air craft. To estimate the change in terrain height during recovery, the slope is extrapolated for a time T_{gr} which is calculated as a function

of initial flight path angle. The formula for T_{gr} is:

$$T_{gr} = \frac{2V}{g\sqrt{n^2+1}} \tan^{-1} \frac{\sqrt{(n^2+1)}\tan\frac{\gamma}{2}}{n-1}$$

where:

T_{gr} = time used to calculate ground rise

V = aircraft velocity (ft/sec)

g = 32.2 ft/sec

n = 4 (G's)

γ = aircraft flight path angle

Once T_{gr} has been determined, the following checks are made to determine whether or not to calculate ground rise.

1. Calculate T_{impact}

$$T_{impact} = \frac{\text{Height}}{V_z(\text{terrain}) - V_z(\text{aircraft})}$$

where T_{impact} = the time it will take the aircraft to hit the terrain based on its current vertical velocity ($V_{z(aircraft)}$) and the current rate of ground rise ($V_{z(terrain)}$)

Height = current height above terrain

If $T_{impact} < T_{resp}$, ground rise is not calculated.

(T_{resp} = pilot response time, 2 seconds.)

2. Calculate lower boundary for T_{impact}

$$\text{BOUND}_{lwr} = T_{gr} - T_{impact}$$

3. Calculate upper boundary for T impact

$$\text{BOUND}_{upr} = T_{gr} + 10 \text{ Seconds}$$

4. If T_{impact} falls between Bound_{lwr} and Bound_{upr}, ground rise is calculated:

Ground rise (ΔZ_{gr}) is simply calculated as:

$$\Delta Z_{gr} = (V_{z(terrain)}) \cdot (T_{gr})$$

LAWS ALGORITHM ANALYSIS

The Fairchild LAWS Algorithm continuously compares the aircraft's present height above the ground with the altitude required for recovery. The algorithm inputs, predictive warning mechanization, and inhibits are discussed below.

INPUTS: Inputs to the LAWS algorithm are as follows: inertial velocities (Vx, Vy, Vz), pitch and bank angles (theta, phi), and an "inop" signal from the Inertial Navigation System (INS); calibrated airspeed (Vc), mach (M), and an "inop" signal from the Central Air Data Computer (CADC); filtered signals of Vz, radar altitude (Hr), and rate of change of Vz and radar altitude from a low-pass (alpha-beta) filter. The filter receives inputs from the INS and radar altimeter, creates rate information, performs extrapolation logic and outputs signals to the "inop" lights.

OUTPUTS: Outputs from the algorithm are a LAWS "inop" signal and a warning cue which activates the voice box. The "inop" signal denotes the radar altitude has broken lock for more than one second while inside the radar map.

WARNING COMPUTATION: The warning algorithm consists of two parts; a predictive warning calculation and a minimum design altitude (MDA) warning calculation. There are two types of inhibits: those which block a predictive warning and those which block all warnings.

PERSISTENCE: The predictive warning must persist for 0.46 seconds (23 frames for a 50 Hz operation) to activate the warning signal to the pilot. The MDA warning must persist 0.06 seconds (3 frames) before a warning is issued. There is an added 0.14 second delay in the activation of the voice signal.

MINIMUM DESIGN ALTITUDE: The MDA warning is issued when the aircraft descends below 90 feet AGL (the altitude that the aircraft should never penetrate).

PREDICTIVE WARNING: The predictive portion of the algorithm issues a warning based on a prediction of the time necessary for recovery based on pilot reaction time, flight path angle, MDA, bank angle, airspeed, and terrain slope. The predictive part issues a warning if the sum of the following predictive factors is greater than the radar altitude.

i. HD = dynamic altitude effect (This accounts for altitude lost until pilot reacts, includes a bank angle factor, and includes an empirical determination for g-onset.).

ii. HBD = dynamic biases (This accounts for MDA, bank angle, flight path angle, airspeed, and contains a mach correction factor. This factor contains many empirically chosen correction factors.).

iii. HM = dive recovery factor (This calculates recovery arc to get to flight path parallel to terrain and is a simplistic calculation based on a constant g, constant velocity, dive recovery.).

iv. HT = terrain extrapolation equation (This accounts for terrain growth based on slope of terrain and is a hybrid of both rolling and diving type of maneuvers to arrive at predicted horizontal travel across terrain during recovery.).

PREDICTIVE WARNING INHIBITS: A predictive warning is inhibited if any of the following conditions are true:

i. The dive angle is shallow (less than five degrees down) and aircraft bank angle is outside of the 75 to 110 degree region. This ridge clip inhibit is based on the fact that a 90 foot roll call would give the pilot approximately two seconds to recover. The pilot is situationally aware unless he is in the high bank region in which case he will get approximately 300 feet of altitude at the warning. In addition, there is a high improbability of CFIT for this circumstance.

ii. The slope of terrain is steep. History shows a chance of a CFIT for steep terrain is small.

iii. The rate of closure is not excessive (less than 200 feet/second down), and upward acceleration is sufficiently positive (at least 10 feet/second^2), indicating the pilot has already initiated a recovery.

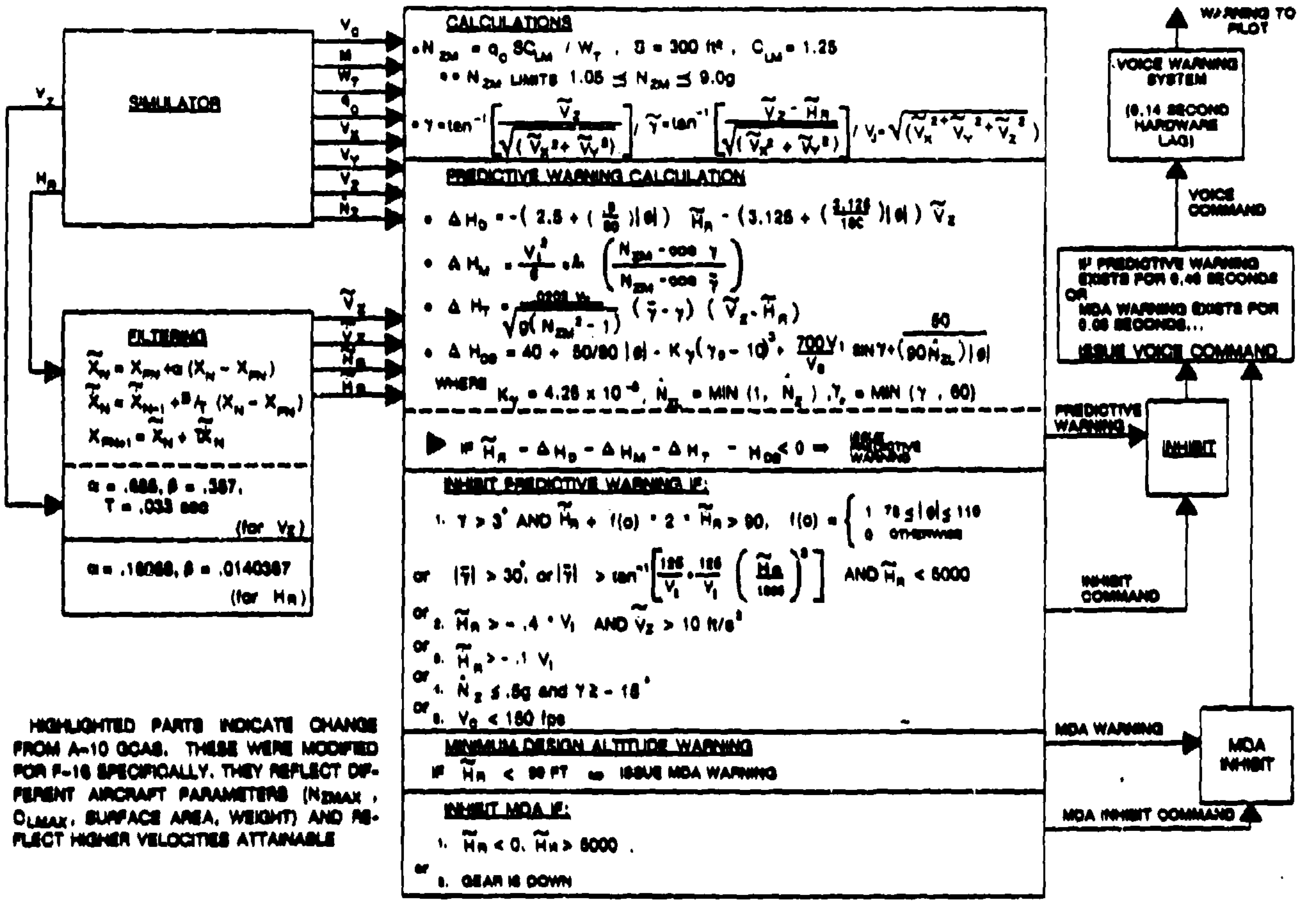
iv. The rate of closure is small (less than 10% of total velocity). When the difference between the flight path angle and ground slope is approximately six degrees or less, the closure rate is slow enough to preclude a predictive warning.

v. The aircraft is in a bunt maneuver (load factor 0.5 "G", dive angle 15 degrees, and bank angle 30 degrees). This type of maneuver occurs only as a result of deliberate pilot action. Since the warning system is based on Visual Flight Reference (VFR), and CFITs occur when the pilot has lost track of his air-to-ground relationship, a warning would likely be a "nuisance" call for this instance.

vi. The velocity is less than 150 knots. Slow speeds like this typically occur only during landing.

TAKE-OFF AND LANDING: For take-off, LAWS is activated after the gear is up and the altitude ascends past 115 feet. This same logic follows for a go-around. Landing is handled by blocking the warning when the gear is down and the altitude is less than 1500 feet.

LAWS ALGORITHM USED FOR F-16 SIMULATION, ENECH NOV 88



HIGHLIGHTED PARTS INDICATE CHANGE FROM A-10 GCAS. THESE WERE MODIFIED FOR F-16 SPECIFICALLY. THEY REFLECT DIFFERENT AIRCRAFT PARAMETERS (N_{ZMAX}, C_{LMAX}, SURFACE AREA, WEIGHT) AND REFLECT HIGHER VELOCITIES ATTAINABLE

DEFINITION OF TERMS

qc	Dynamic pressure	$\tilde{X}n$	Filtered value
Nzm	Maximum load factor available	$\tilde{\dot{X}}n$	Filtered value for rate
CLM	Maximum coefficient of lift	Xpn	Predicted filter value
Wt	Weight	$\tilde{H}r$	Radar altitude (filtered)
S	Wing area	$\tilde{\dot{H}}r$	Radar altitude Rate (Filitered)
γ	Flight path angle	Vc	Calibrated airspeed
$\tilde{\gamma}$	Terrain slope	VI	Intertial velocity
$\dot{N}z$	Load factor	M	Mach

APPENDIX B

MISSION 15
LOW LEVEL NAV/POP-UP DELIVERIES

OBJECTIVE: Evaluate the GCAS effectiveness during low altitude tactical navigation/weapons delivery.

SCENARIO: This is a combined nav/weapons delivery profile. There are three targets planned for straight ahead pop-up deliveries. The targets are fairly easy to see: a bridge, a ship, and an airfield. The area is heavily defended. If you climb above 800 feet AGL, you will get a "SAM" warning.

START:
Altitude: 2100 feet MSL (500 feet AGL)
Airspeed: 480 knots
Heading: 054 Degrees
Weapons: 6 Mk 82's/Pairs/RP 1/CCIP

INSTRUCTIONS:

1. Fly 480 knots Groundspeed or the speed required to make your TOT. Turns are 60 degrees bank. Stay at 300 AGL except during weapons delivery. Maintain 480 feet during target run on.
2. Weapons Delivery:

TGT	Pull-Up	Pull-Down	Release
1 (Bridge)	30 degrees at 20 sec	4100 feet	2600 feet
2 (Ship)	30 degrees at 20 sec	4000 feet	2500 feet
3 (Airport)	30 degrees at 20 sec	4000 feet	2500 feet

3. If you get a pull-up warning, recover and continue the mission at the planned altitude.
4. If you get a warning during NAV leg, evaluate it as either:

   A. Valid
   B. Invalid, expected
   C. Invalid, unexpected

MISSION 16
IMC MANEUVERING

OBJECTIVE: Evaluate the system's effectiveness in recovering from situations where spatial disorientation is a factor.

SCENARIO: You will perform a number of aerobatic maneuvers in IMC.

NOTE: A non-standard HUD Bank display will be used to help your attitude awareness.

INSTRUCTIONS

1. Stay within 10 nmi of steerpoint "1". Try to work back and forth between STPT 1 and 2.
2. Perform the following maneuvers:

	A/S	ALT (feet)	Gs	POWER
Split S	300	8000	Gs and power as required to maintain 300 knots.	
Loop	500	3000	5	MIL
Cuban 8	500	3000	5	MIL
Sliceback	350	8000	3-5	MIL
Double Split S	300	14000	Gs and power as required to maintain 300 knots.	

3. If you get a pull-up warning, complete the recovery to a safe altitude above 5000 feet and set up for the next maneuver.

MISSION 17
RANGE MISSION AND LOW LEVEL DEFENSIVE TURNS

OBJECTIVE: Evaluate the algorithms during a complex range mission and during hard, low level, defensive turns.

SCENARIO: This is your first trip to the Berrysburg Bombing Range. You are trying out a number of alternate run-ins for straight ahead pop-up deliveries. Because of a peculiar local airspace restriction, you must remain at or below 500 AGL except in the target area. Following the third delivery pass, proceed direct to Steerpoint 11 where you will practice hard defensive turns at low altitude. You will fly a figure 8 pattern between Millersburg and Elizabethville. To keep you honest, a "SAM" threat warning will sound each time you go above 800' AGL.

START:

Altitude: 1800' MSL

Airspeed: 480 knots

Heading: 199 degrees

Weapons: 4 MK 82's, stns 3 and 7,

CCIP/Singles RP - 1

INSTRUCTIONS:

1. Make 3 straight ahead pop-up attacks on the Berrysburg target.

2. The sequence of the runs is on your map. After each run, fly to the bend in the river and then along Hooflander Mountain.

3. If you are in doubt, follow the steerpoints. Console operator will help.

4. Make tight turns (at least 3 Gs).

5. Start your pull-up when you are 20 seconds from target.

   - pull up 30 degrees.

   - pull down at 4000' MSL (30 degrees).

   - release at 2500' MSL.

   - do your best not to abort the pass -- even if you feel a bit steep (unless you get a pull-up warning).

6. Stay in NAV Master Mode until you are on run-in heading, then select A/G.

7. You will be asked to perform additional tasks during the mission.

8. If you get a pull-up warning, recover and continue the mission.

9. After the last delivery run, proceed direct to steerpoint 11, 480 KCAS at low level to establish the figure 8 pattern.

10. At each steerpoint, make a hard (5-G) turn back toward the next steerpoint.

11. Always turn toward the north, away from the mountains.

12. Each time you turn, you will be instructed to read a series of numbers and letters from a card located above your head to simulate checking 6. Try to maintain your G-load and altitude while you read the data.

13. If you get a warning, recover and continue.

APPENDIX C

GROUND COLLISION AVOIDANCE SYSTEM PILOT QUESTIONNAIRE

INSTRUCTIONS: The purpose of this questionnaire is to obtain information from you about your previous flying experience. Your answers to these questions will help us in our evaluation of this simulation. Your honest opinions are, therefore, essential and will be kept confidential.

If you have any questions, please ask the questionnaire administrator for assistance. Take as much time as necessary to answer the questionnaire.

PERSONAL DATA:

Name (last, first, mi): ______________________________

Rank: ______________________________

Duty AFSC: ______________________________

Organization and Symbol: ______________________________

Duty Station: ______________________________

Duty Phone: ______________________________

Wing Commander, Squadron Commander, DO: ______________________________

Aero Rating: ______________________________

Age: ______________________________

Height: ______________________________

Weight: ______________________________

Vision, Corrected: ______________ Uncorrected: ______________

Years in Military Service: ______________________________

What type(s) of aircraft have you flown? (List)

Aircraft: ______________________________

Fighter hours: ______________________________

F-16 Hours: ______________________________

Hours Flying with Radar Altimeter: ______________________________

Total Flight Time (Include Student Hours): ______________________________

GCAS DAILY SCHEDULE - 1

DAY 1 (Monday)

0800 - 0830	Welcome and simulation overview
0830 - 0900	Facility/simulator tour
0910 - 1000	Systems and mission brief
1010 - 1100	Cockpit familiarization
1110 - 1200	Fly familiarization
1200 - 1300	BREAK
1300 - 1500	Data collection flights

Day 2 (Tuesday)

0800 - 1200	Data collection flights
1300 - 1700	Data collection flights

DAY 3 (Wednesday morning)

0800 - 1100	Data collection (as required)
1100 - 1200	Debrief and questionnaire

* Pilot #1 will fly two missions the first hour.
Pilot #2 will fly two missions the second hour.
Pilot #1 will fly two missions the third hour.
Pilot #2 will fly two missions the fourth hour.

** 3 data sessions = 12 sorties

GCAS DAILY SCHEDULE - 2

DAY 1 (Wednesday afternoon)

1300 - 1330	Welcome and simulation overview
1330 - 1400	Facility/simulator tour
1410 - 1500	Systems and mission brief
1510 - 1600	Cockpit familiarization
1610 - 1700	Fly familiarization

DAY 2 (Thursday)

0800 - 1200	Data collection flights
1300 - 1700	Data collection flights

DAY 3 (Friday)

0800 - 1200	Data collection flights
1300 - 1600	Data collection flights (as required)
1600 - 1700	Debrief and questionnaire

* Pilot #1 will fly two missions the first hour.

Pilot #2 will fly two missions the second hour.

Pilot #1 will fly two missions the third hour.

Pilot #2 will fly two missions the fourth hour.

** 3 data sessions = 12 sorties

PILOT QUESTIONNAIRE DATA

1. Do you feel the "Pull-up" warning alarms were initiated for the most part:

	GROUND CLOBBER		GCAS		LAWS		ENHANCED GC	
TOO EARLY	4/15	27.0%	4/16	25.0%	2/16	12.5%	0/8	0.0%
SLIGHTLY EARLY	1/15	6.7%	1/16	6.0%	1/16	6.5%	2/8	25.0%
JUST RIGHT	8/15	53.0%	9/16	57.0%	10/16	62.5%	4/8	50.0%
SLIGHTLY LATE	0/15	0.0%	1/16	6.0%	1/16	6.25%	1/8	12.5%
TOO LATE	2/15	13.3%	1/16	6.0%	2/16	12.5%	1/8	12.5%

2. How often did you get nuisance warnings?

	GROUND CLOBBER		GCAS		LAWS		ENHANCED GC	
ALL THE TIME	1/15	6.7%	2/16	12.5%	0/16	0.0%	1/8	12.5%
MOST OF THE TIME	2/15	13.3%	2/16	12.5%	0/16	0.0%	0/8	0.0%
OCCASIONALLY	2/15	13.3%	3/16	18.8%	2/16	12.5%	1/8	12.5%
SELDOM	5/15	33.3%	7/16	43.7%	4/16	25.0%	4/8	50.0%
NEVER	5/15	33.3%	2/16	12.5%	10/16	62.5%	2/8	25.0%

3. Did the Warning System get your attention?

	GROUND CLOBBER		GCAS		LAWS		ENHANCED GC	
YES, ALL THE TIME	16/22	73.0%	21/24	87.5%	19/24	79.2%	6/8	75.0%
YES, MOST OF THE TIME	6/22	27.0%	3/24	12.5%	5/24	20.8%	2/8	25.0%
OCCASIONALLY	0/22	0.0%	0/24	0.0%	0/24	0.0%	0	0.0%
SELDOM	0/22	0.0%	0/24	0.0%	0/24	0.0%	0	0.0%
NEVER	0/22	0.0%	0/24	0.0%	0/24	0.0%	0	0.0%

4. Were there any instances, in your opinion, where the system provided no warning when it should have?

O GROUND CLOBBER

NO 12/22
YES 10/22

oo Level flight into rising terrain.
oo Wings level at low dive angles.

oo Hit ridge without a warning.
oo Descending with bank >90 had no warning.

O GCAS

NO 14/23
YES 9/23

oo Level flight into rising terrain
oo Ridge clip

O LAWS

NO 16/24
YES 8/24

oo Hit ridge without a warning
oo No warning when overbanked

NO 4/8

YES 4/8

oo Wings level descent of 2 - 4 resulted in crash without warning.
oo Level flight into rising terrain
oo Hit ridge with no warning

5. ADDITIONAL COMMENTS:

O GROUND CLOBBER

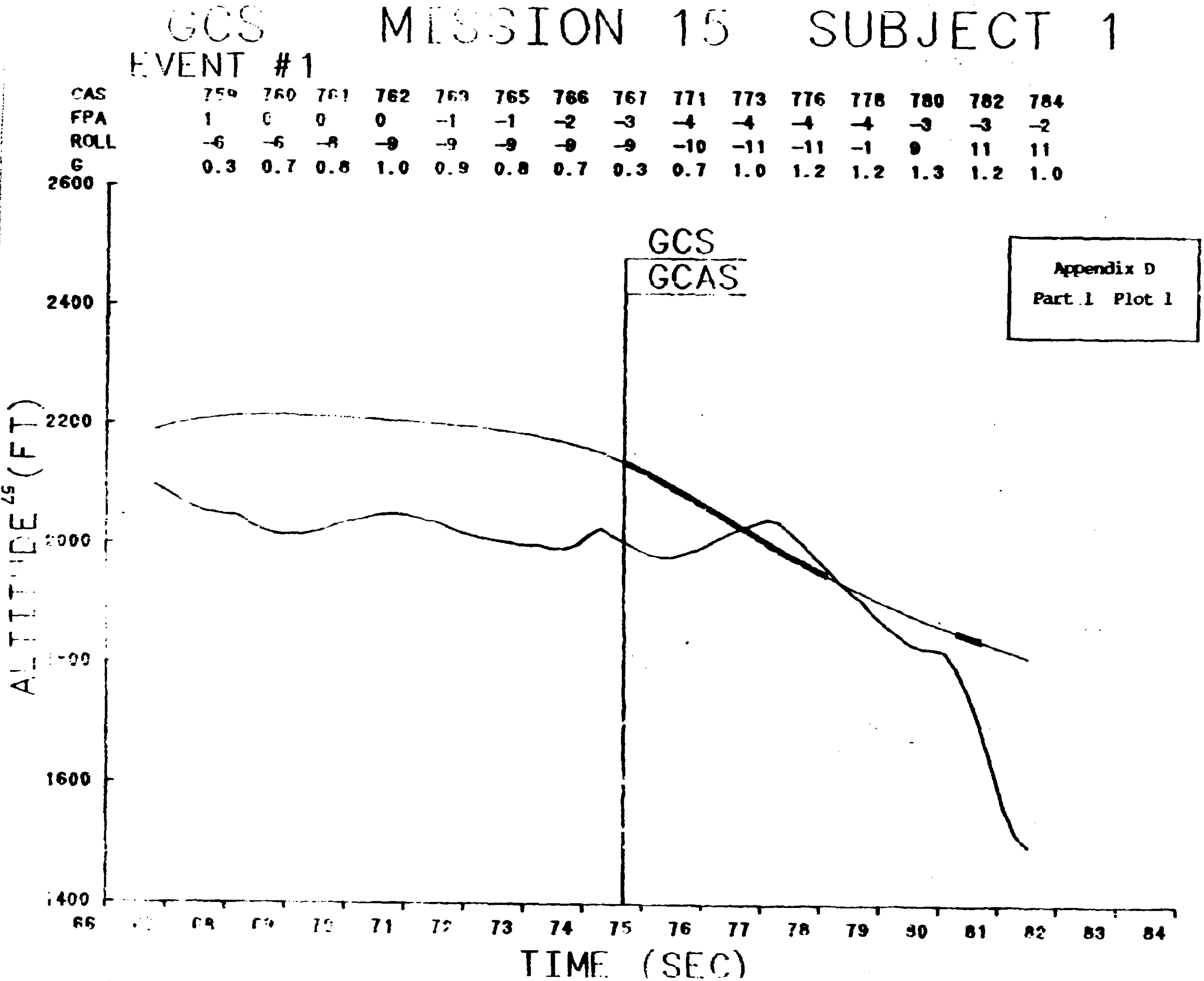
oo Anticipation cue is a plus (5).
oo Anticipation cue could be a bit longer.
oo Confused the anticipation cue with fuze aiming symbol.
oo Warning was early during high dives.
oo Most warnings occurred during bunts.

O GCAS

oo Pushing over the backside of ridges you often get false warnings (2).
oo Warnings initiated slightly early.
oo Several nuisance warnings in a row for no apparent reason.

O LAWS

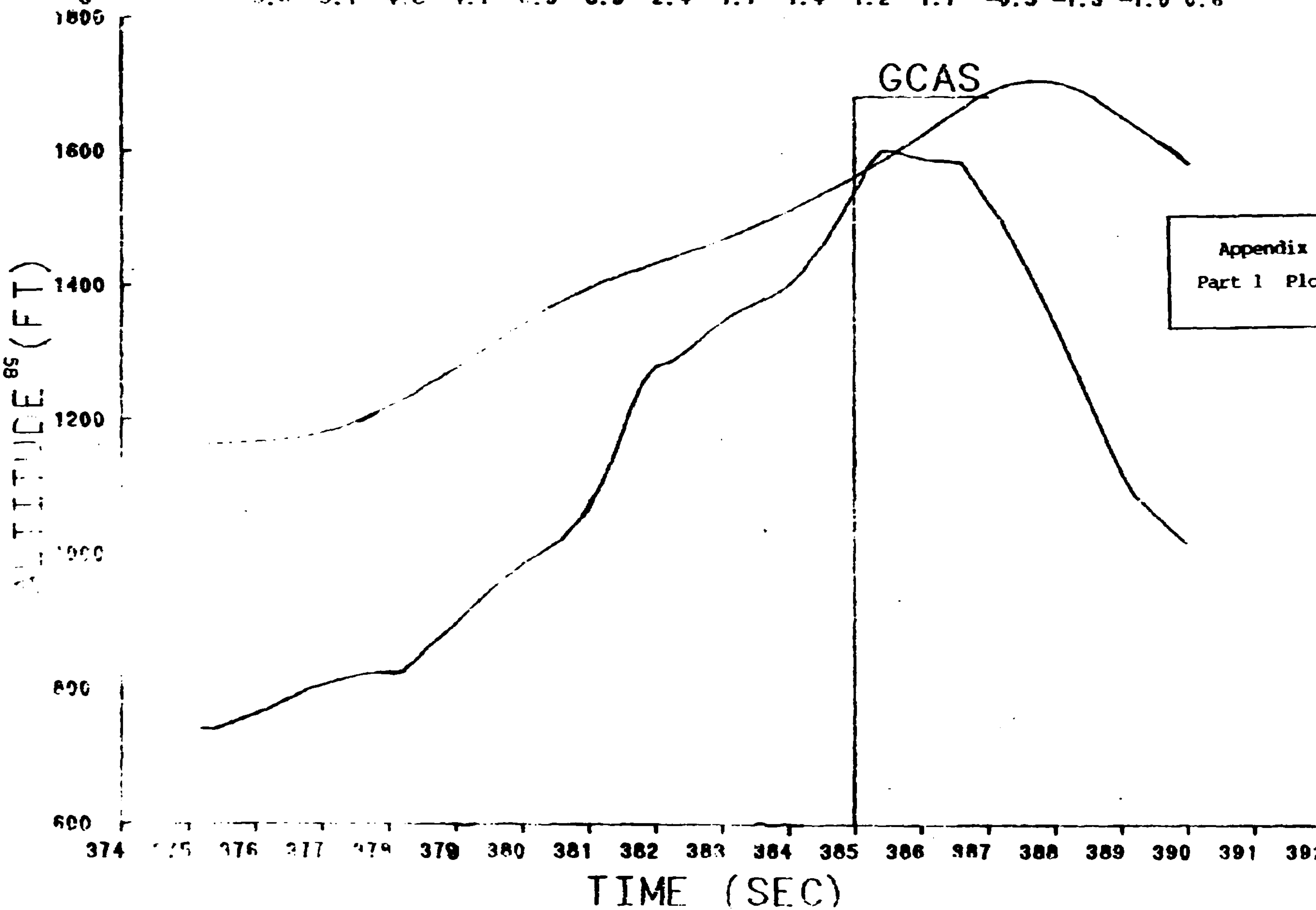
oo When manuevering over ridge lines and through mountain gaps I'd seldom-to-never get a warning.
oo Generally felt warning system provided good warnings against gradually rising terrain or due to inattention.
oo Nuisance warnings on bombing.


GCS MISSION 15 SUBJECT 1
EVENT #1
CAS 759 760 761 762 763 765 766 767 771 773 776 778 780 782 784
FPA 1 0 0 0 -1 -1 -2 -3 -4 -4 -4 -4 -3 -3 -2
ROLL -6 -6 -8 -9 -9 -9 -9 -9 -10 -11 -11 -1 9 11 11
G 0.3 0.7 0.8 1.0 0.9 0.8 0.7 0.3 0.7 1.0 1.2 1.2 1.3 1.2 1.0
GCS
GCAS
Appendix D
Part 1 Plot 1
ALTITUDE (FT)
2600
2400
2200
2000
1600
1400
66
68
71
73
74
75
76
77
78
79
80
81
82
83
84
TIME (SEC)

MISSION 15 SUBJECT 3

EVENT #1

CAS	809	801	795	795	779	777	776	779	782	786	788	791	790	792	801
FPA	0	2	4	5	5	3	2	3	4	4	5	4	−1	−5	−6
ROLL	−78	−68	−71	−75	−82	−84	−71	−41	−23	−8	−2	−2	−2	−2	0
G	5.6	5.1	4.8	4.7	3.9	3.9	2.4	1.7	1.4	1.2	1.7	−0.5	−1.3	−1.0	0.6

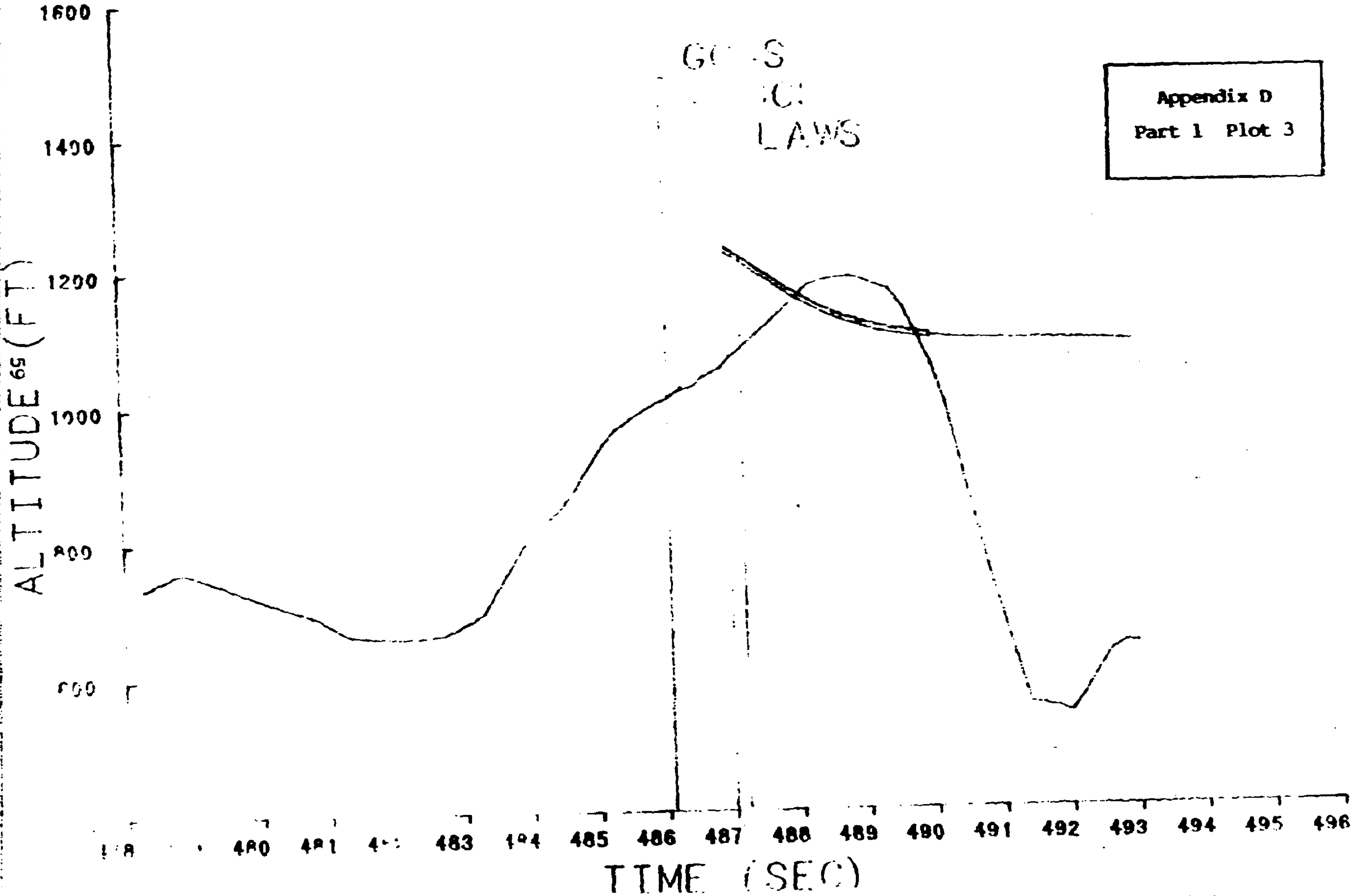


Appendix D
Part 1 Plot 2

MISSION 15 SUBJECT 4

EVENT #1

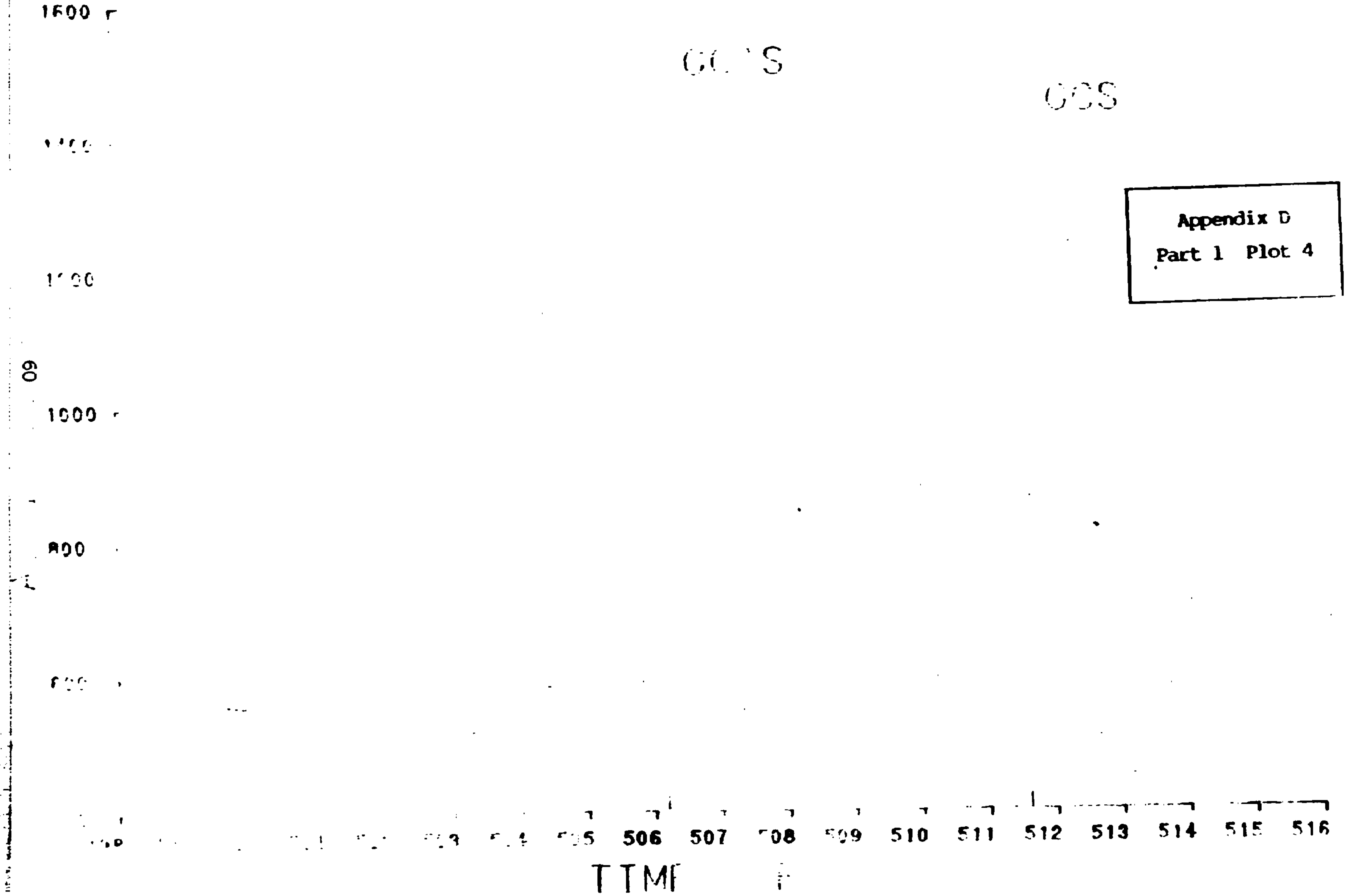
CAS	901	900	898	896	894	891	889	890	893	896	897	897	897	898	898
FPA	0	2	4	5	5	3	−1	−3	−4	−4	−2	−1	0	0	0
ROLL	−46	−26	−19	−17	−15	−15	−28	−30	−44	−40	−37	−41	−42	−43	−48
G	[illegible]	1.8	2.5	1.5	0.8	−0.1	−0.3	−0.3	0.7	3.1	2.7	1.7	1.5	1.2	1.5



Appendix D
Part 1 Plot 3

GCS MISSION 15 SUBJECT 4

CAS	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	899	898	892	886	879	878	878	879	881	883
FPA	0	0	[illegible]	0	-1	-3	-5	-4	-1	1	1	0	-4	-6	-2
ROLL	[illegible]	-59	-47	56	84	90	83	64	63	66	70	17	12	6	5
G	1.7	2.0	1.9	1.3	1.8	3.0	4.3	4.9	5.2	3.2	2.0	0.0	-0.4	1.0	3.7

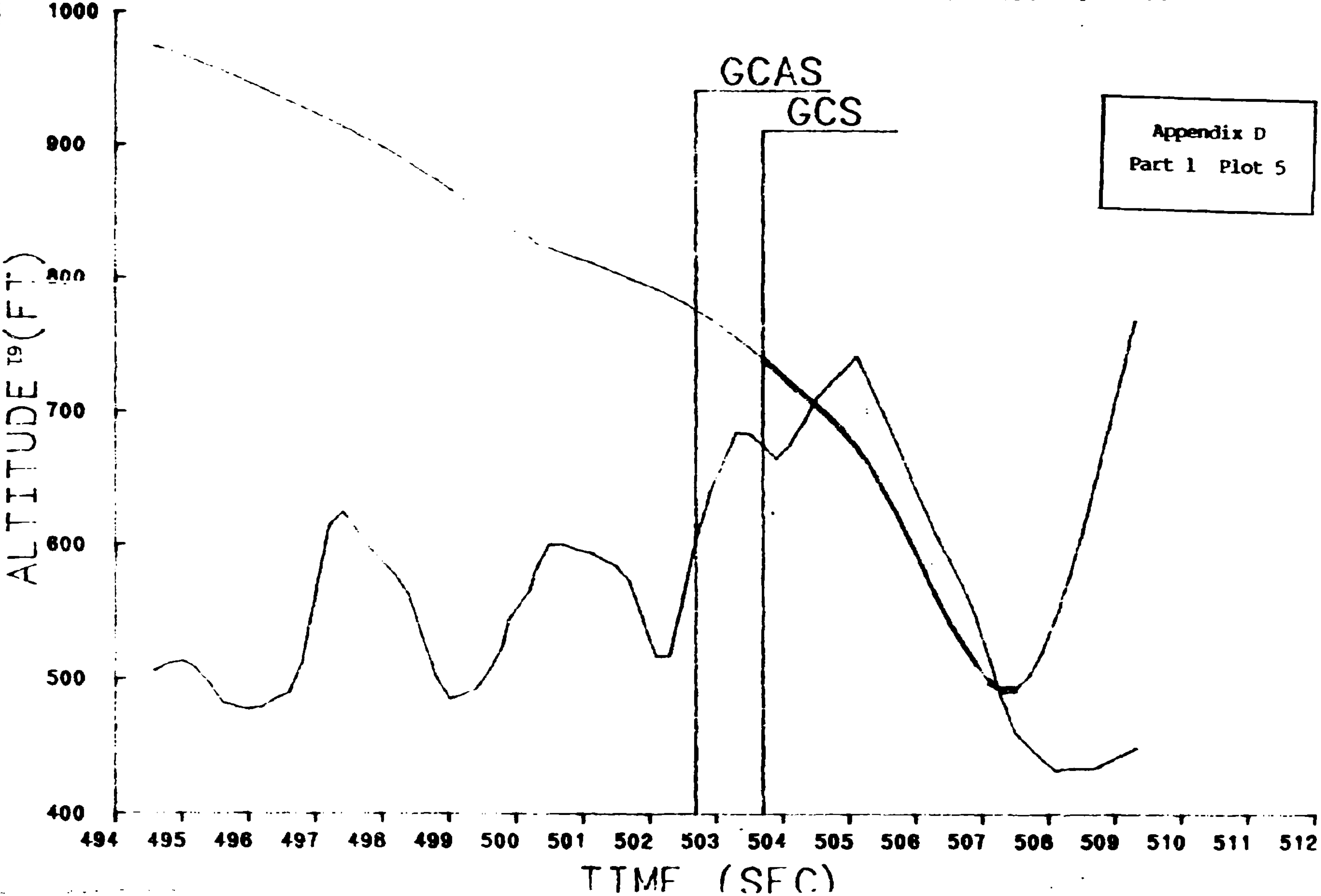


Appendix D
Part 1 Plot 4

GCS MISSION 15 SUBJECT 6

EVENT #2

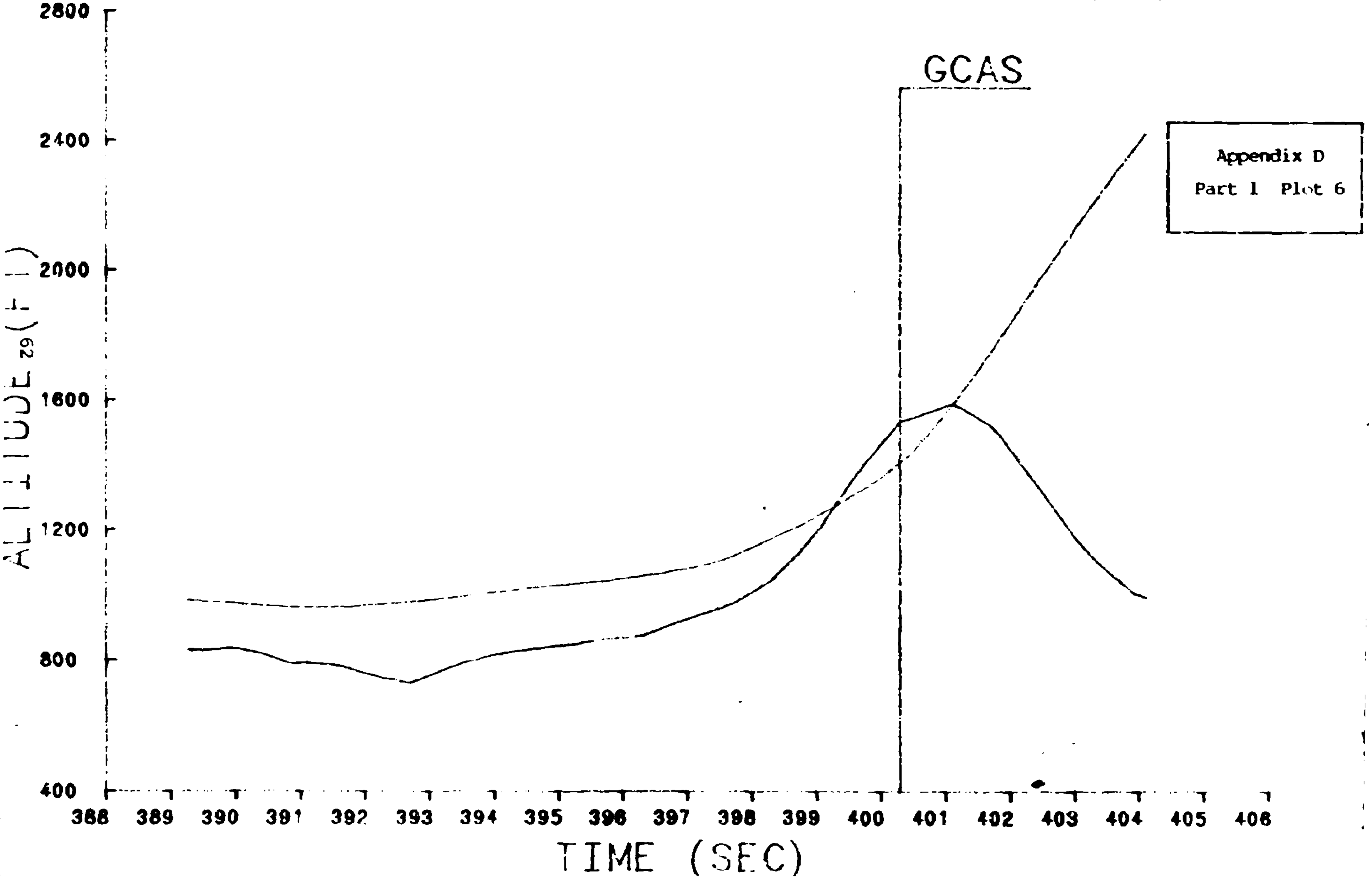
CAS	1068	1068	1061	1043	1027	1012	1000	992	986	981	974	971	955	932	922
FPA	-1	-1	-1	-2	-2	-1	-1	-1	-2	-2	-5	-6	-1	10	13
ROLL	-22	-19	-17	-67	-67	-63	-70	-73	-69	0	107	56	-15	11	3
G	0.-	1.0	1.1	1.8	2.9	3.2	2.5	2.1	2.0	0.9	2.7	2.5	6.6	4.4	1.0



GCS MISSION 15 SUBJECT 6

EVENT #1

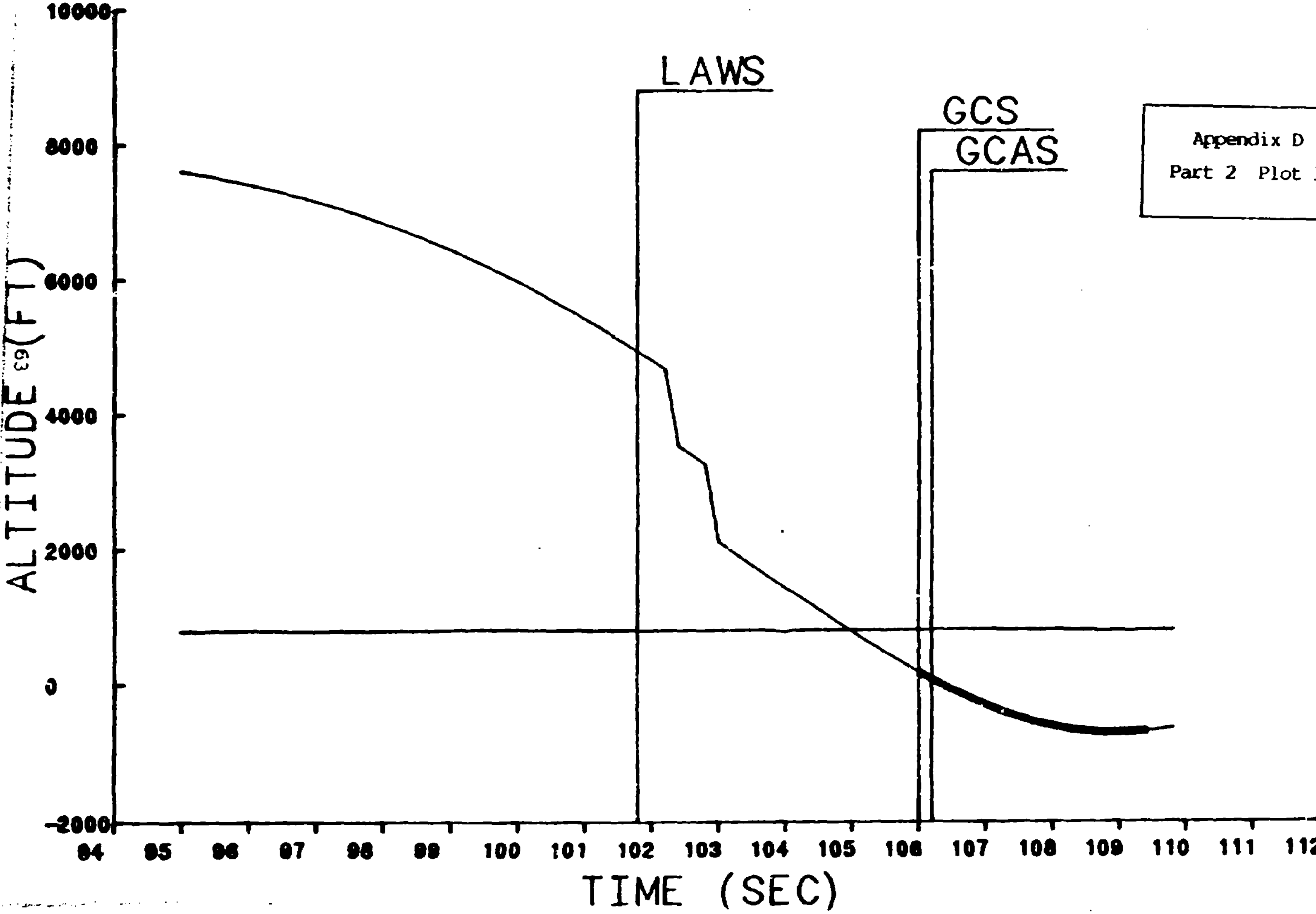
CAS	887	887	887	886	886	886	885	882	875	869	862	847	838	830	824
FPA	-1	0	1	2	2	1	2	3	6	7	10	18	21	19	18
ROLL	-63	-58	-60	-62	-65	-67	-64	-61	-64	-61	-39	-6	-30	-64	-65
G	1.9	2.9	2.9	2.2	2.1	2.5	2.8	3.6	3.5	3.9	5.3	3.3	1.0	0.9	0.8



GCS MISSION 16 SUBJECT 2

EVENT #1

CAS	602	611	619	635	650	667	682	689	700	702	699	691	661	607	544
FPA	−20	−26	−34	−42	−50	−58	−69	−82	−83	−69	−55	−40	−24	−4	15
ROLL	175	179	178	−178	179	178	174	−26	−6	−5	−3	−1	−8	−7	−3
G	0.9	1.2	1.6	2.1	2.2	2.5	4.3	5.0	5.7	6.0	6.1	6.2	7.9	6.0	6.0

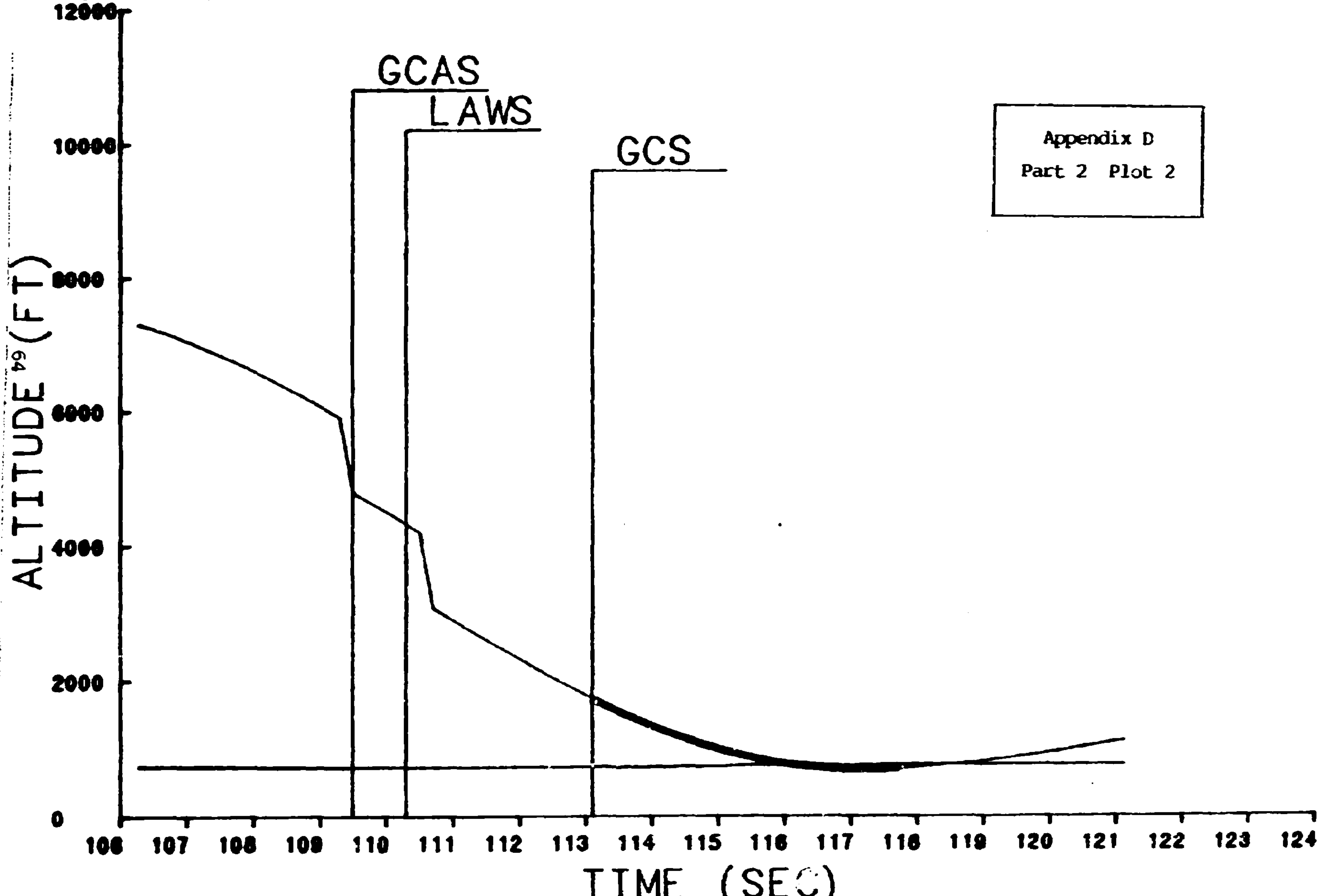


Appendix D
Part 2 Plot 1

GCS MISSION 16 SUBJECT 3

EVENT #1

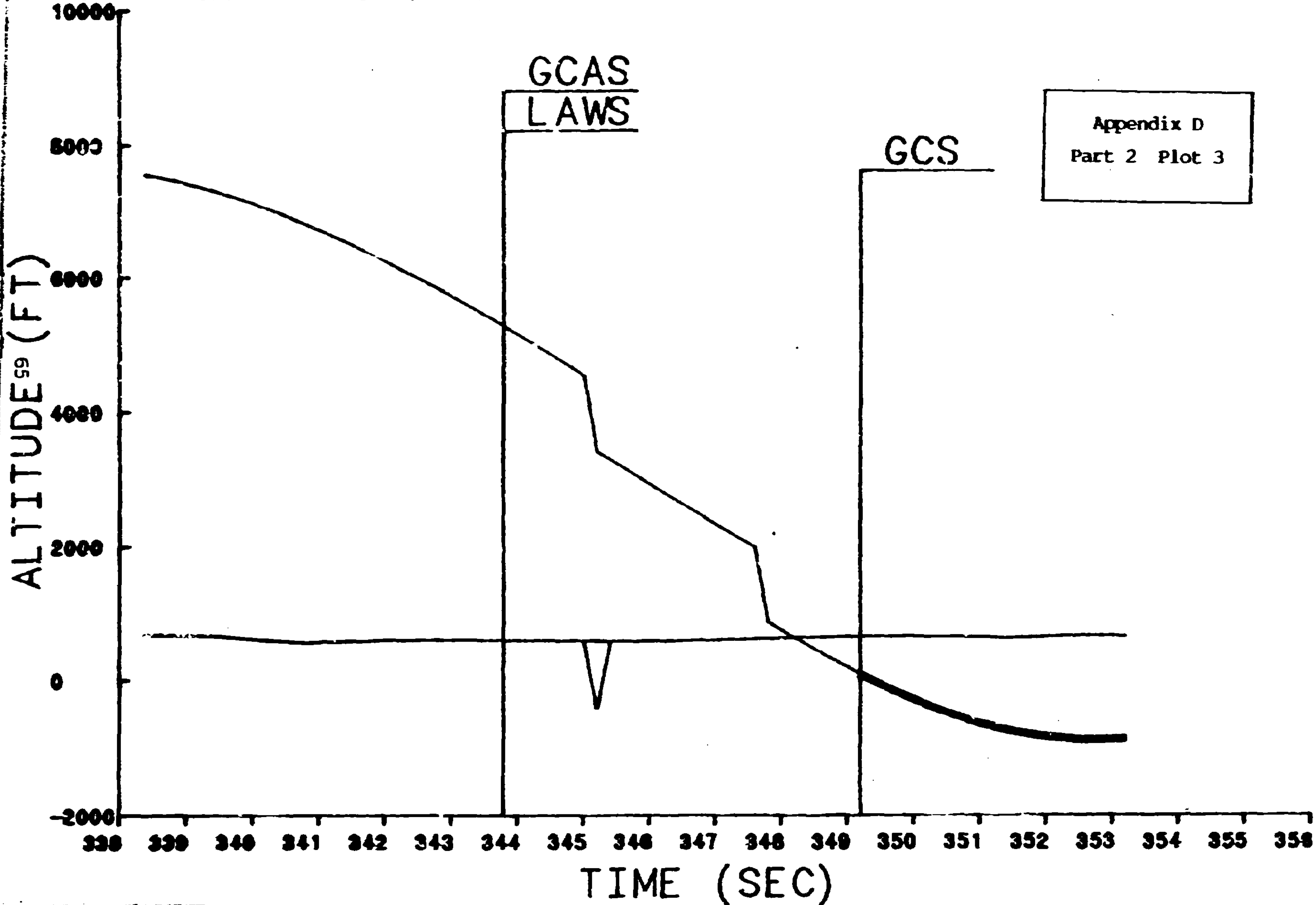
CAS	595	593	594	597	600	600	597	590	574	558	510	479	463	442	425
FPA	-42	-57	-71	-85	-82	-68	-55	-42	-29	-15	-2	9	15	19	22
ROLL	177	173	165	6	2	2	1	1	1	0	0	-1	-2	-3	-4
G	4.0	4.2	4.3	4.4	4.6	4.8	4.8	4.6	5.5	5.2	4.6	3.1	2.5	1.8	1.4



GCS MISSION 16 SUBJECT 3

EVENT #2

CAS	581	583	586	593	600	606	614	620	635	640	638	626	606	581	554
FPA	-28	-39	-51	-61	-71	-79	-80	-75	-70	-63	-53	-40	-25	-10	4
ROLL	-127	-127	-115	-97	-80	-45	-32	-38	-42	-36	-32	-24	-17	-14	-13
G	3.8	4.1	4.2	4.6	4.8	5.0	5.1	5.0	5.2	5.8	6.1	6.5	6.3	5.9	5.2

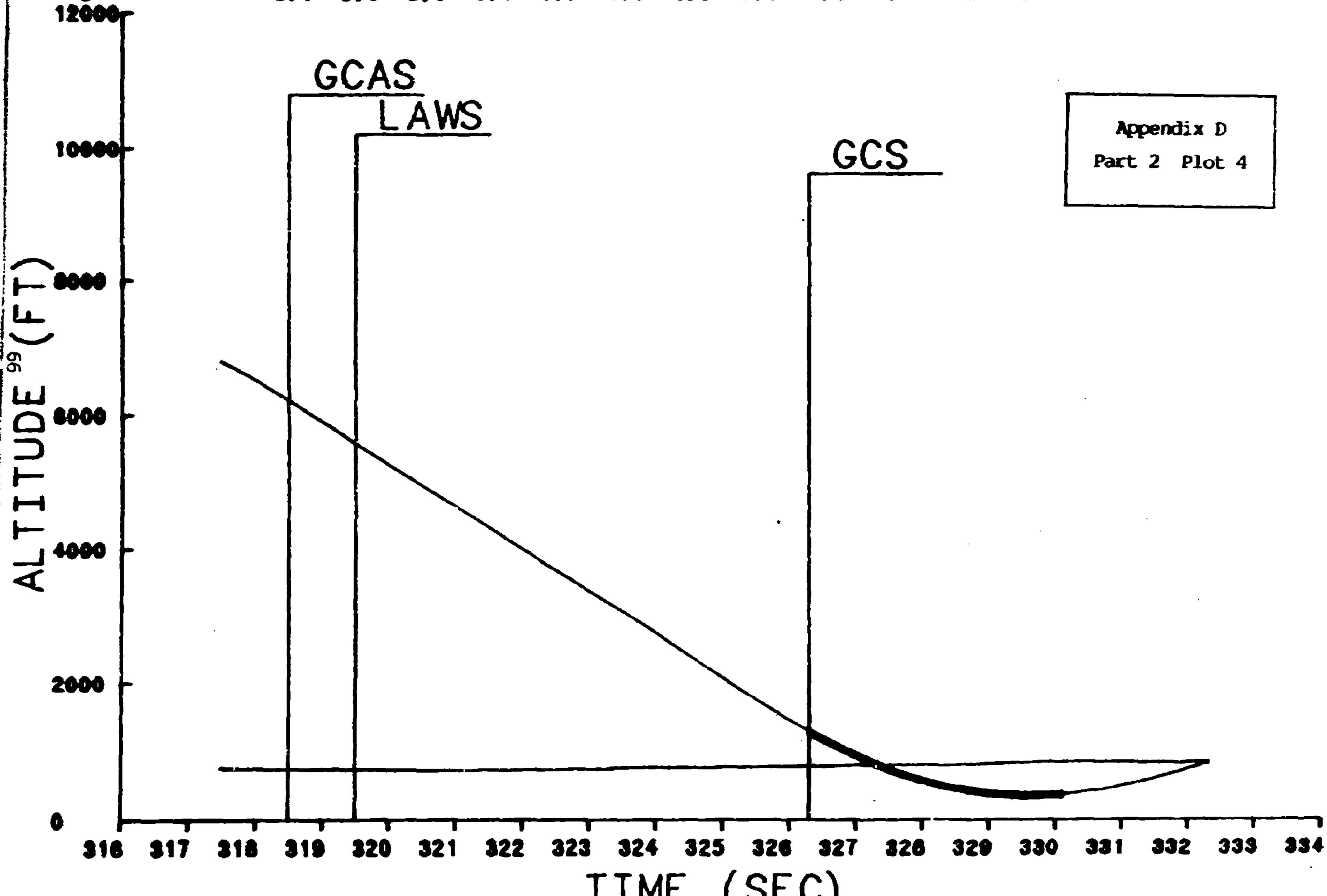


Appendix D
Part 2 Plot 3

GCS MISSION 16 SUBJECT 4

EVENT #1

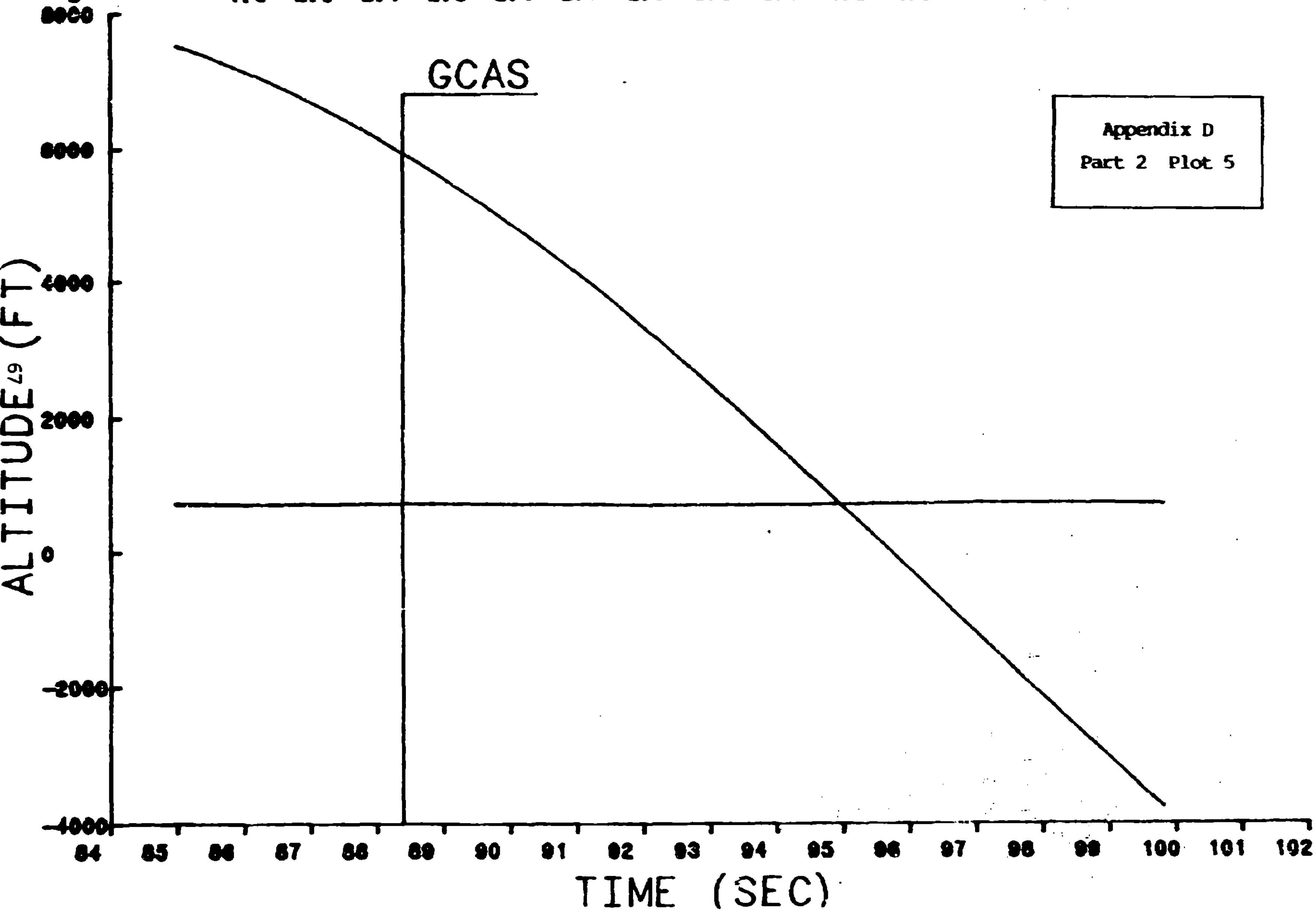
CAS	644	643	650	657	661	665	671	673	658	644	629	590	565	520	497
FPA	-66	-62	-71	-78	-77	-73	-84	-72	-56	-39	-22	-6	10	25	37
ROLL	-102	12	-43	-76	-16	-77	5	28	-26	-5	-11	-10	-7	-4	-6
G	6.1	5.6	5.6	6.1	6.5	6.3	6.5	7.3	7.2	7.1	6.8	6.4	5.8	5.3	3.7



GCS MISSION 16 SUBJECT 5

EVENT #1

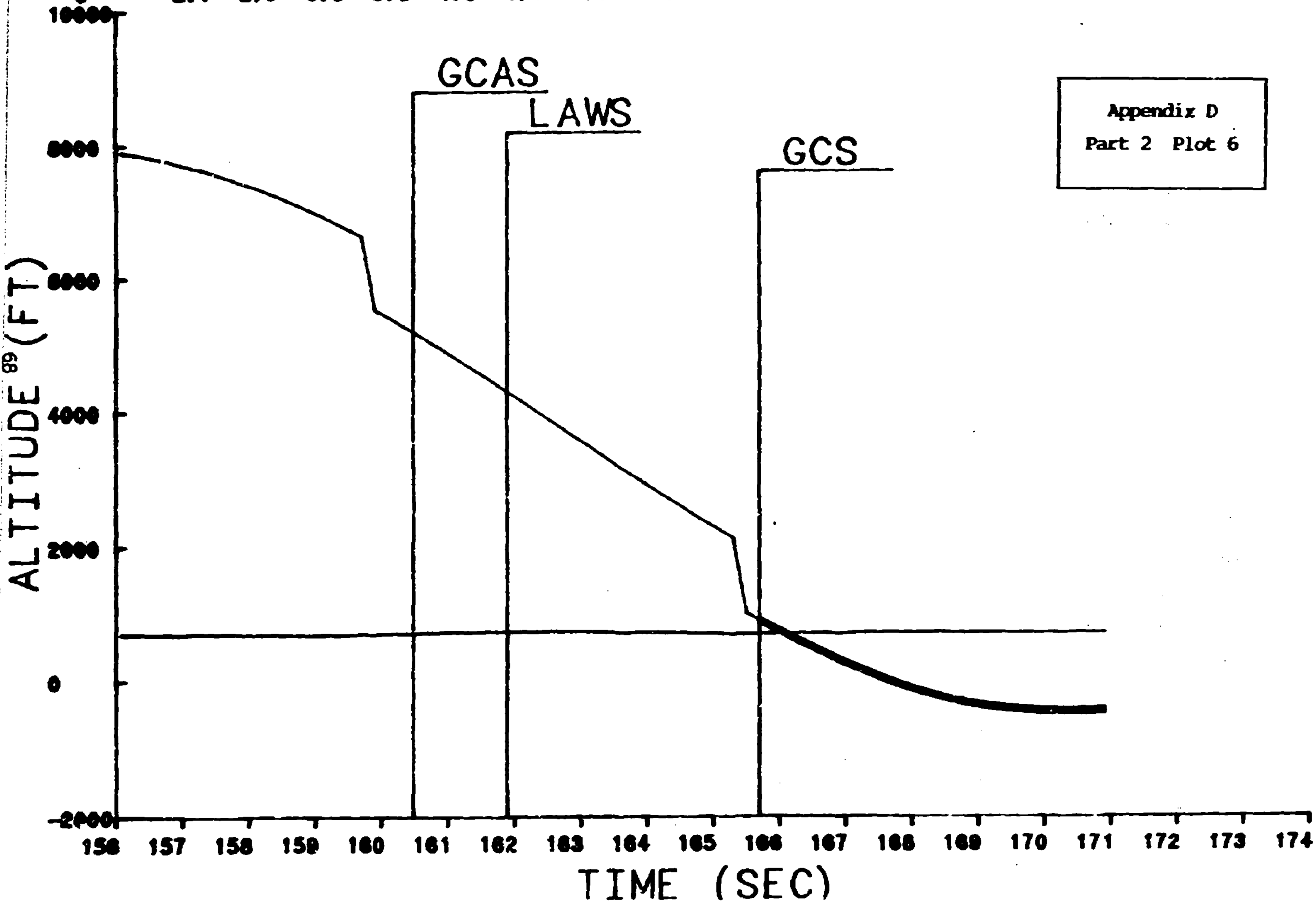
CAS	626	656	687	721	755	790	825	860	894	927	958	985	1001	1017	1033
FPA	-40	-47	-54	-62	-69	-76	-82	-89	-86	-82	-78	-74	-67	-62	-60
ROLL	-179	-180	180	178	179	177	171	17	6	3	2	2	4	3	3
G	1.6	2.0	2.1	2.3	2.4	2.7	2.8	2.8	2.0	2.2	2.3	3.2	4.4	2.1	1.8



GCS MISSION 16 SUBJECT 6

EVENT #1

CAS	602	609	620	633	646	660	672	681	688	692	696	689	668	646	631
FPA	-25	-36	-47	-59	-72	-85	-83	-71	-60	-49	-41	-29	-16	-4	3
ROLL	-178	-176	-177	-177	-178	1	0	0	-1	-1	-1	-2	-2	-1	4
G	2.7	2.9	3.3	3.8	4.3	4.4	4.5	4.6	4.7	4.3	4.7	5.4	5.8	4.6	2.7

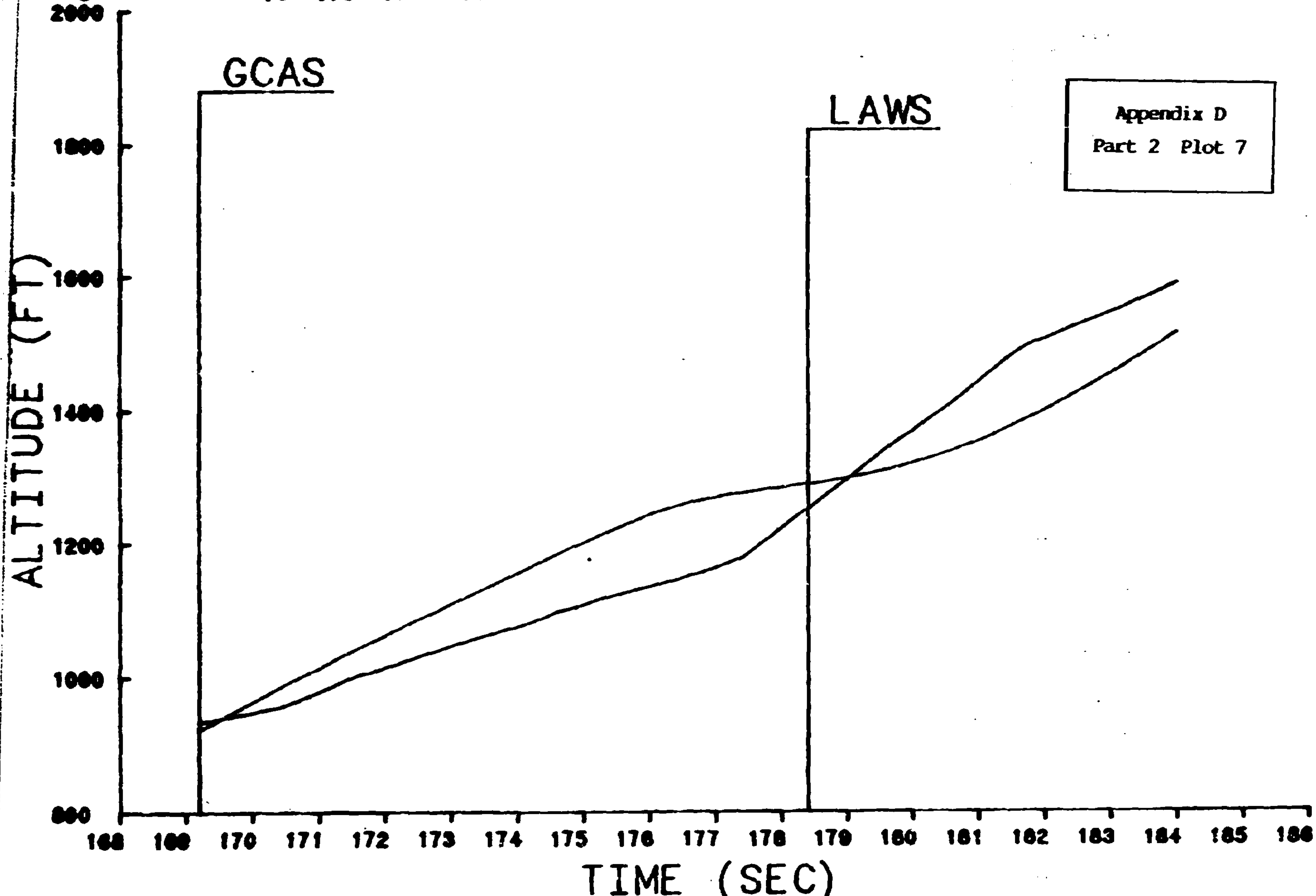


Appendix D
Part 2 Plot 6

GCS MISSION 16 SUBJECT 6

EVENT #2

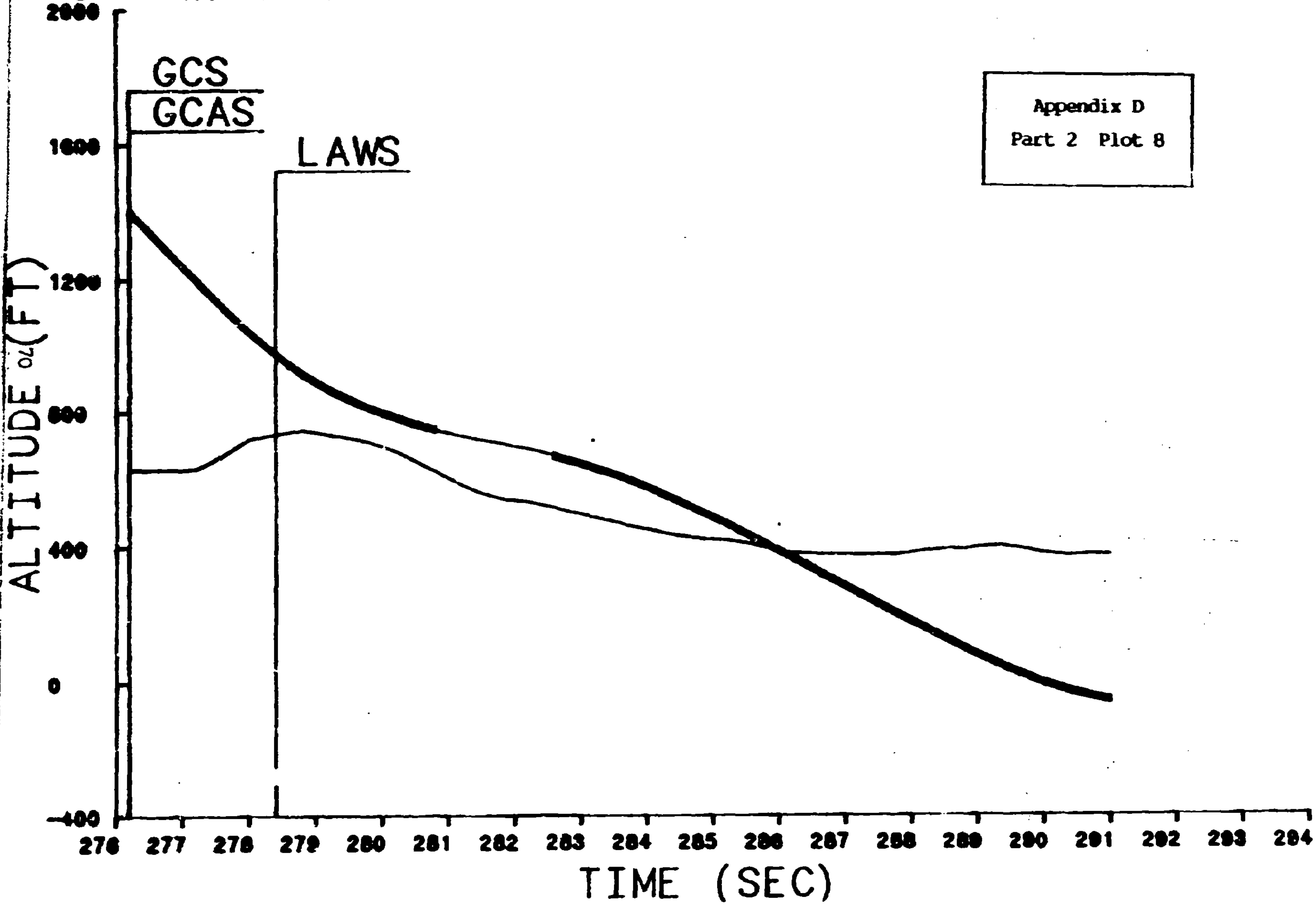
CAS	519	519	520	521	521	522	523	526	528	531	532	523	534	534	533
FPA	6	5	5	5	5	5	4	2	1	2	3	4	5	6	7
ROLL	-2	-8	-6	-9	11	20	25	20	14	7	2	0	-1	-2	8
G	1.0	0.9	0.-	1.0	1.0	1.0	0.6	0.6	1.0	1.3	1.3	1.3	1.3	1.2	1.1



GCS MISSION 16 SUBJECT 6

EVENT #3

CAS	712	718	718	717	715	714	713	713	714	715	717	718	719	719	717
FPA	−17	−15	−10	−6	−4	−3	−5	−7	−8	−8	−6	−8	−8	−6	−3
ROLL	−1	−1	−2	−2	−2	−2	3	4	0	0	0	0	0	0	0
G	1.0	2.5	3.2	2.0	1.6	0.4	0.5	0.1	0.8	0.9	0.9	1.1	1.3	1.5	1.6

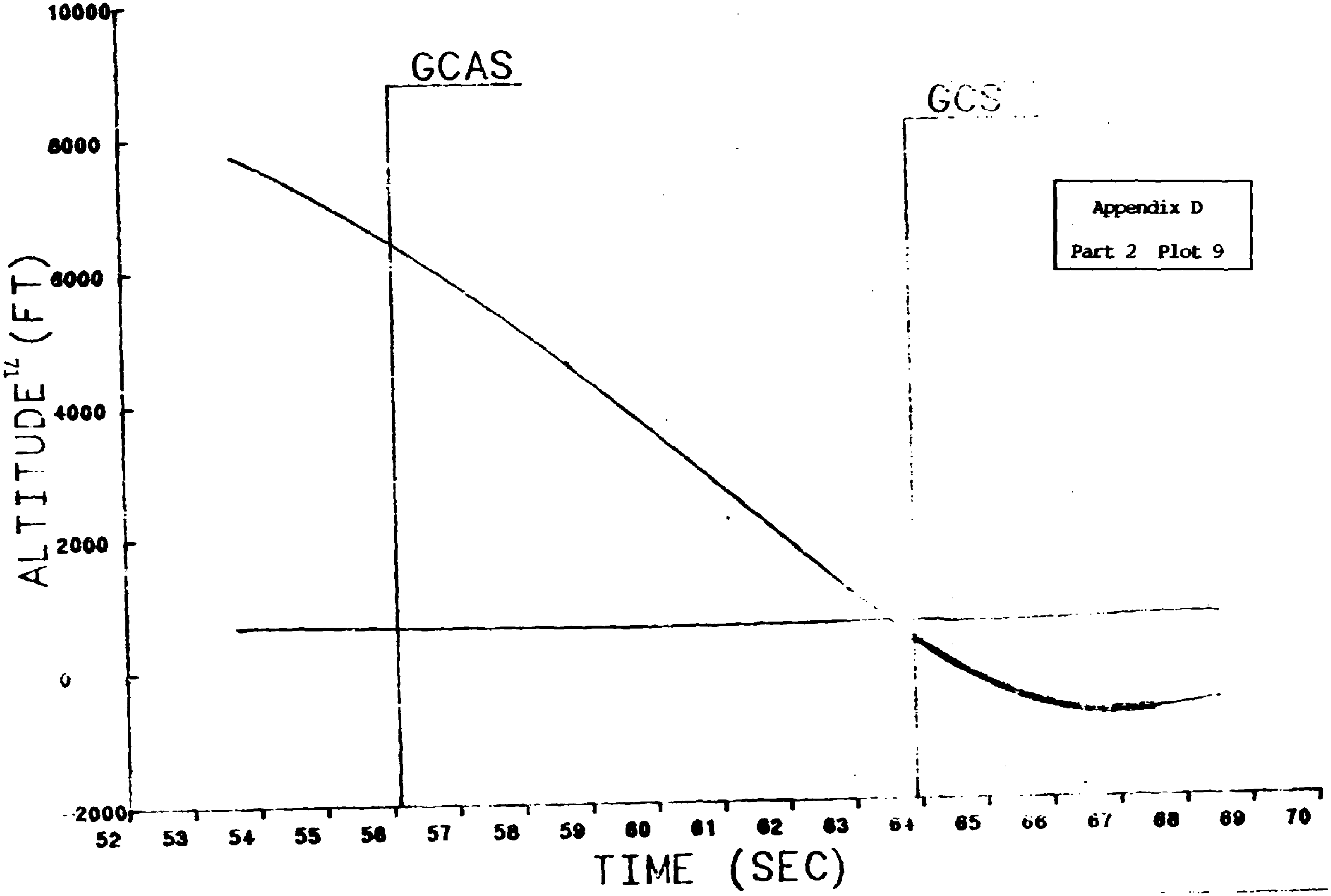


Appendix D
Part 2 Plot 8

GCS MISSION 16 SUBJECT 7

EVENT #1

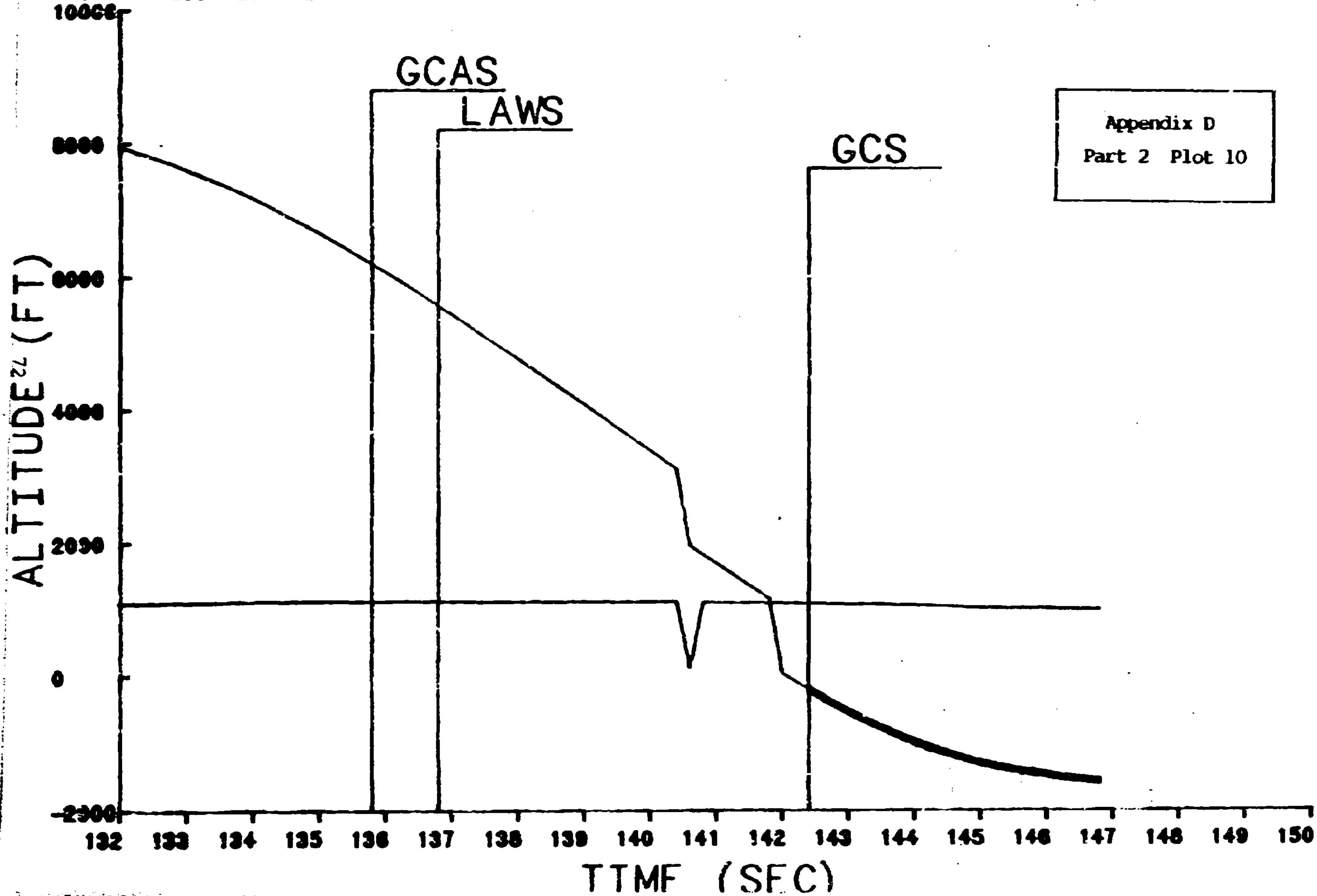
CAS	612	648	686	724	762	799	833	852	890	908	911	901	879	857	851
FPA	-60	-87	-73	-78	-63	-89	-83	-75	-67	-55	-41	-25	-8	8	12
ROLL	170	173	177	180	-179	3	1	0	0	-1	-2	-3	-4	-5	-3
G	2.0	1.9	1.8	1.8	1.7	2.9	4.0	4.2	4.4	7.4	8.3	9.1	9.3	5.1	2.9



GCS MISSION 16 SUBJECT 7

EVENT #2

CAS	555	577	601	626	651	677	703	727	747	763	767	764	755	749	745
FPA	-42	-52	-62	-73	-83	-80	-81	-74	-66	-57	-45	-33	-21	-12	-8
ROLL	177	178	179	179	-171	0	0	-1	-1	-1	-1	-2	-3	-8	-4
G	2.5	2.5	2.9	3.1	3.2	2.8	2.9	3.7	3.8	4.8	5.9	6.1	4.8	3.9	2.4



Appendix D
Part 2 Plot 10

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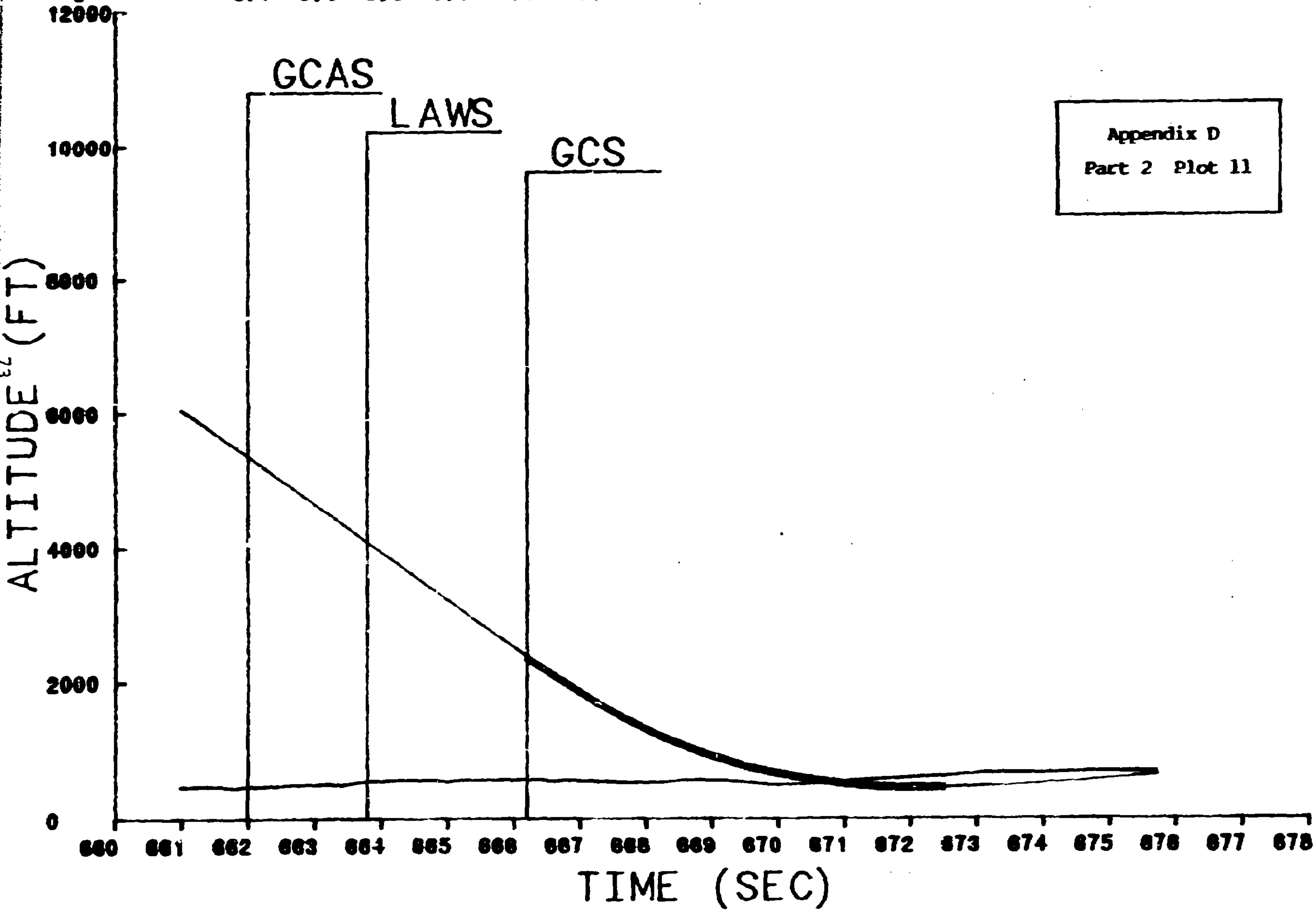
GCS MISSION 16 SUBJECT 7

EVENT #3

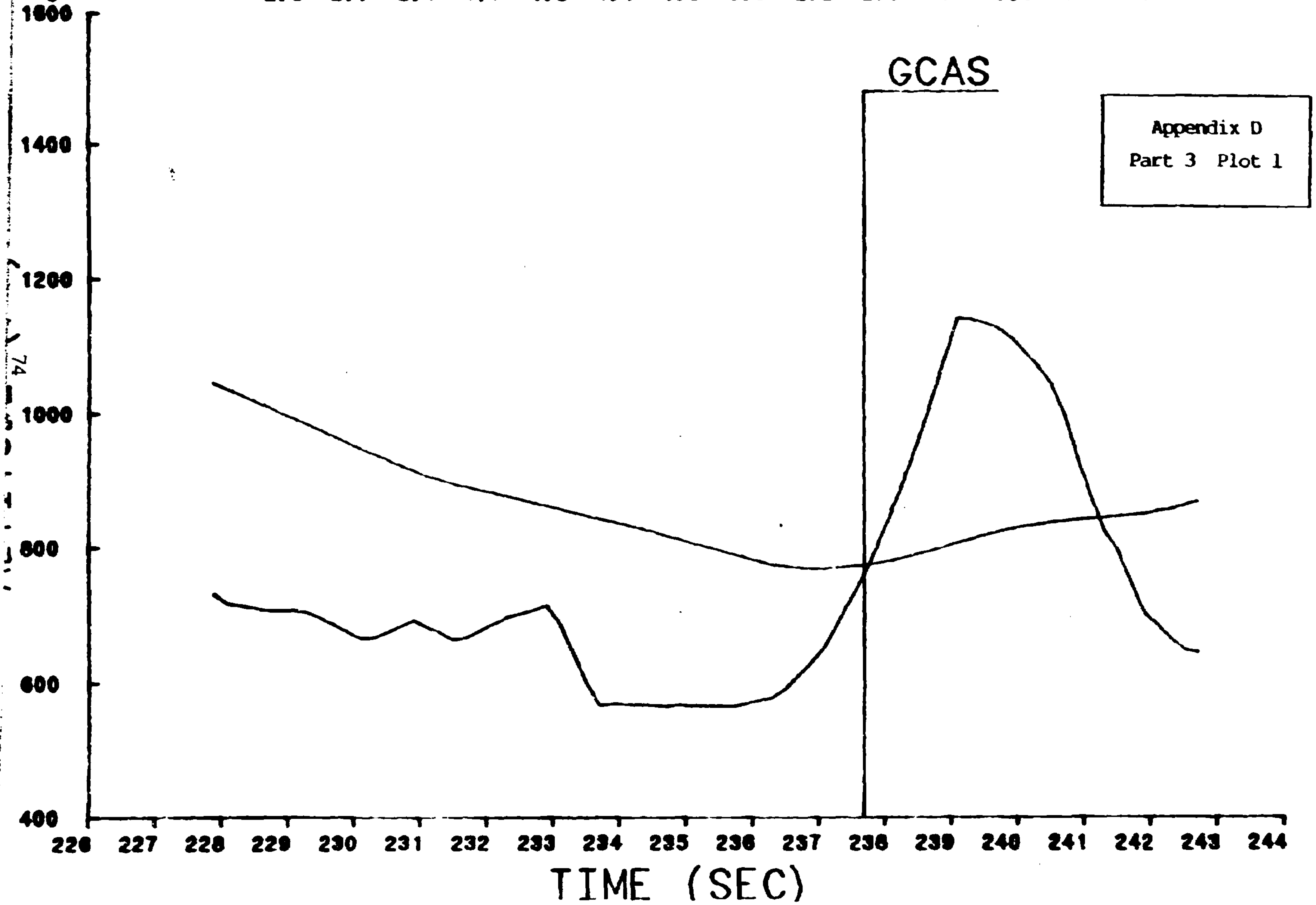
CAS	873	887	902	915	925	938	946	947	947	948	948	944	942	940	938
FPA	-53	-52	-53	-53	-49	-42	-33	-22	-14	-8	-2	2	3	4	4
ROLL	68	77	80	68	50	26	-6	-8	-2	-4	-1	6	5	5	5
G	6.1	5.8	5.6	6.8	6.0	5.0	6.3	6.2	4.5	3.4	4.6	2.0	1.5	1.2	-0.3



GCS MISSION 17 SUBJECT 1

EVENT #1

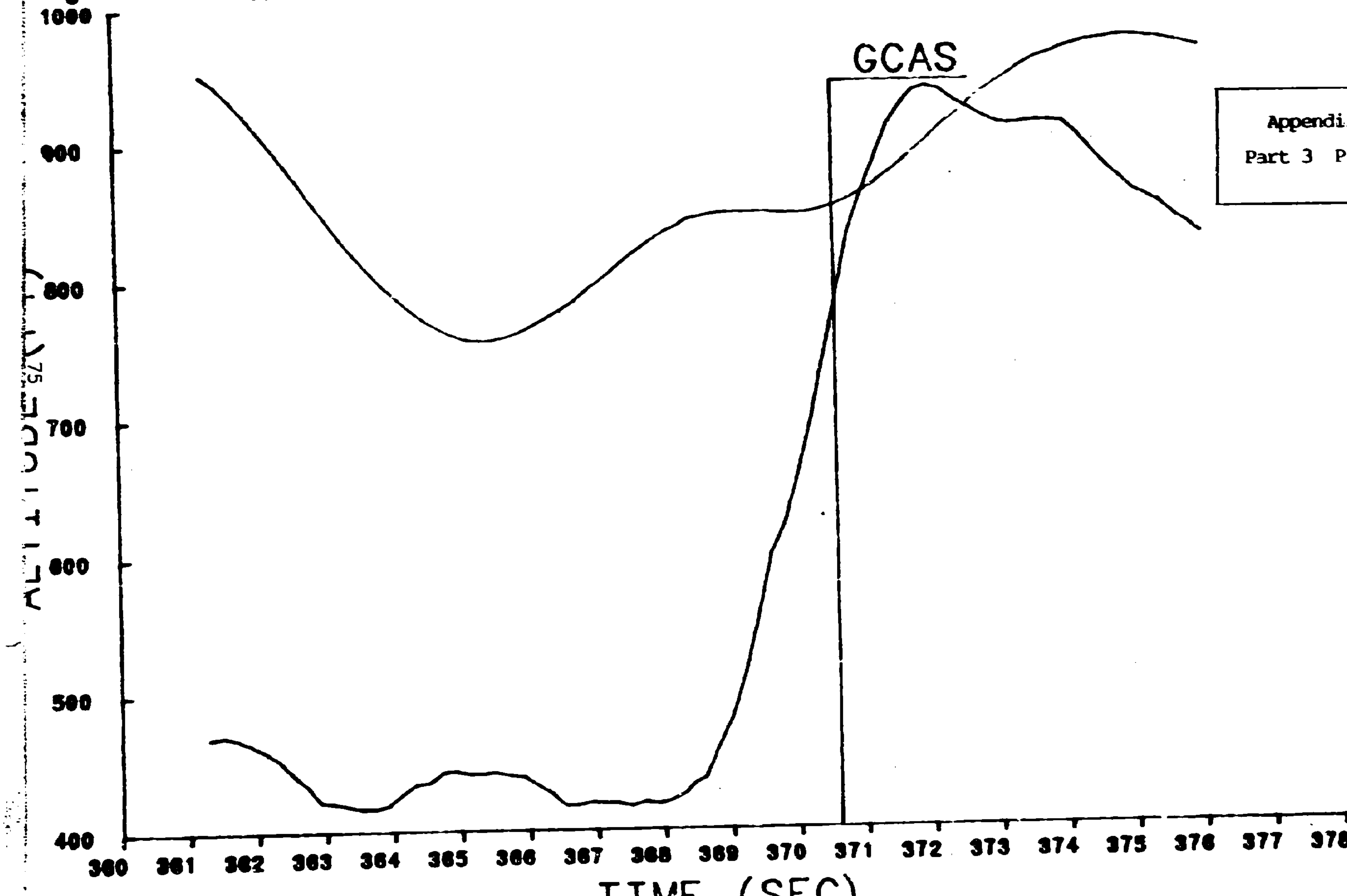
CAS	808	810	813	816	817	822	825	828	830	832	833	833	834	836	835
FPA	-3	-3	-3	-2	-2	-2	-2	-2	-1	1	2	2	1	1	2
ROLL	68	67	56	-14	-46	-20	-8	3	13	13	15	26	43	50	51
G	2.5	2.7	2.4	1.7	1.3	1.1	1.0	0.9	2.2	2.0	1.4	0.6	1.0	2.1	2.7



GCS MISSION 17 SUBJECT 1

EVENT #2

CAS	792	804	812	818	823	827	831	836	839	845	848	850	855	859	863
FPA	−4	−5	−3	−1	2	3	2	0	0	2	3	2	1	0	−1
ROLL	27	26	22	10	7	7	7	7	7	7	9	17	17	17	17
G	0.6	1.3	1.7	2.2	1.7	1.2	0.2	0.6	1.6	1.8	1.2	0.7	0.3	0.3	0.7

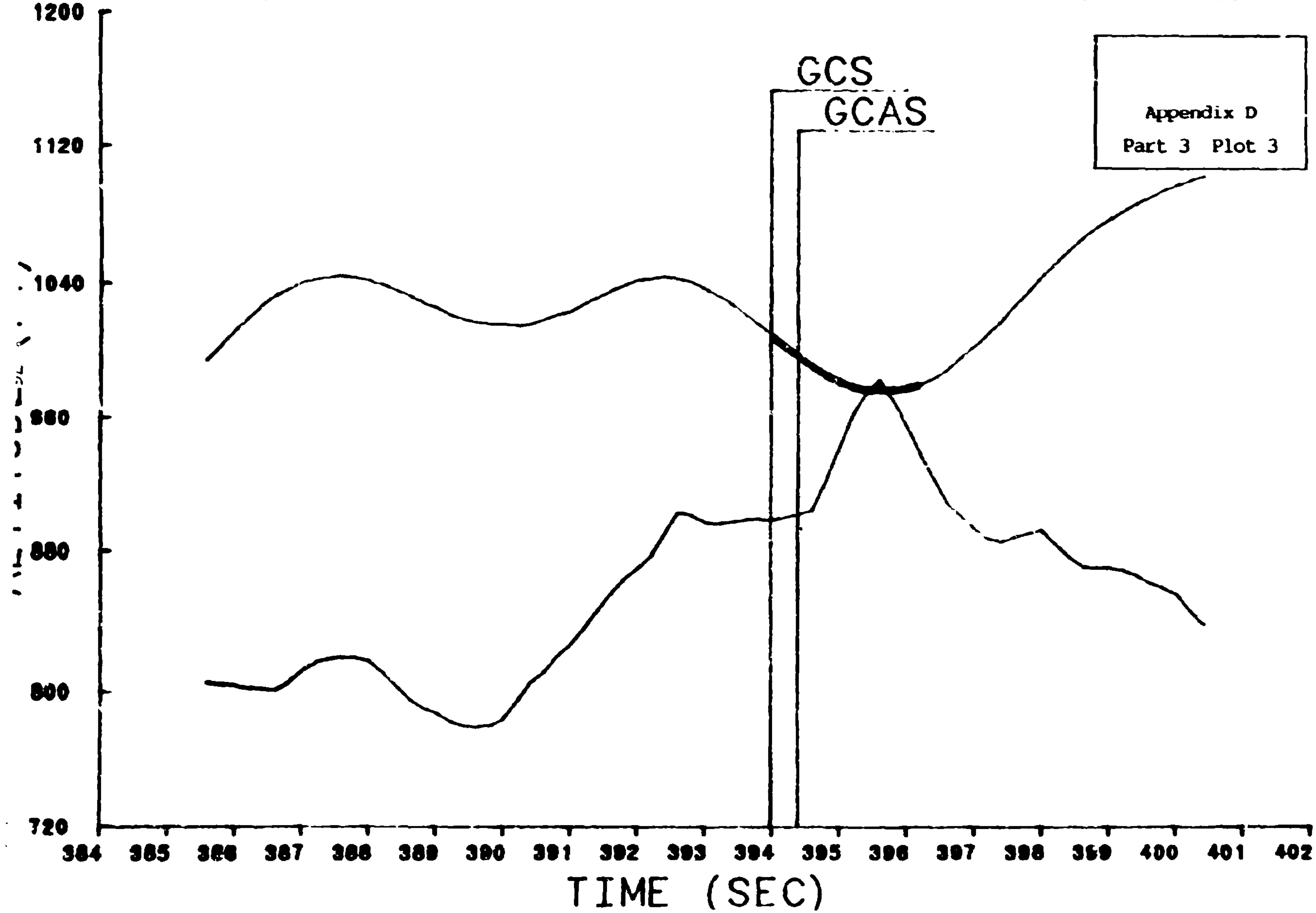


Appendix D
Part 3 Plot 2

GCS MISSION 17 SUBJECT 1

EVENT #3

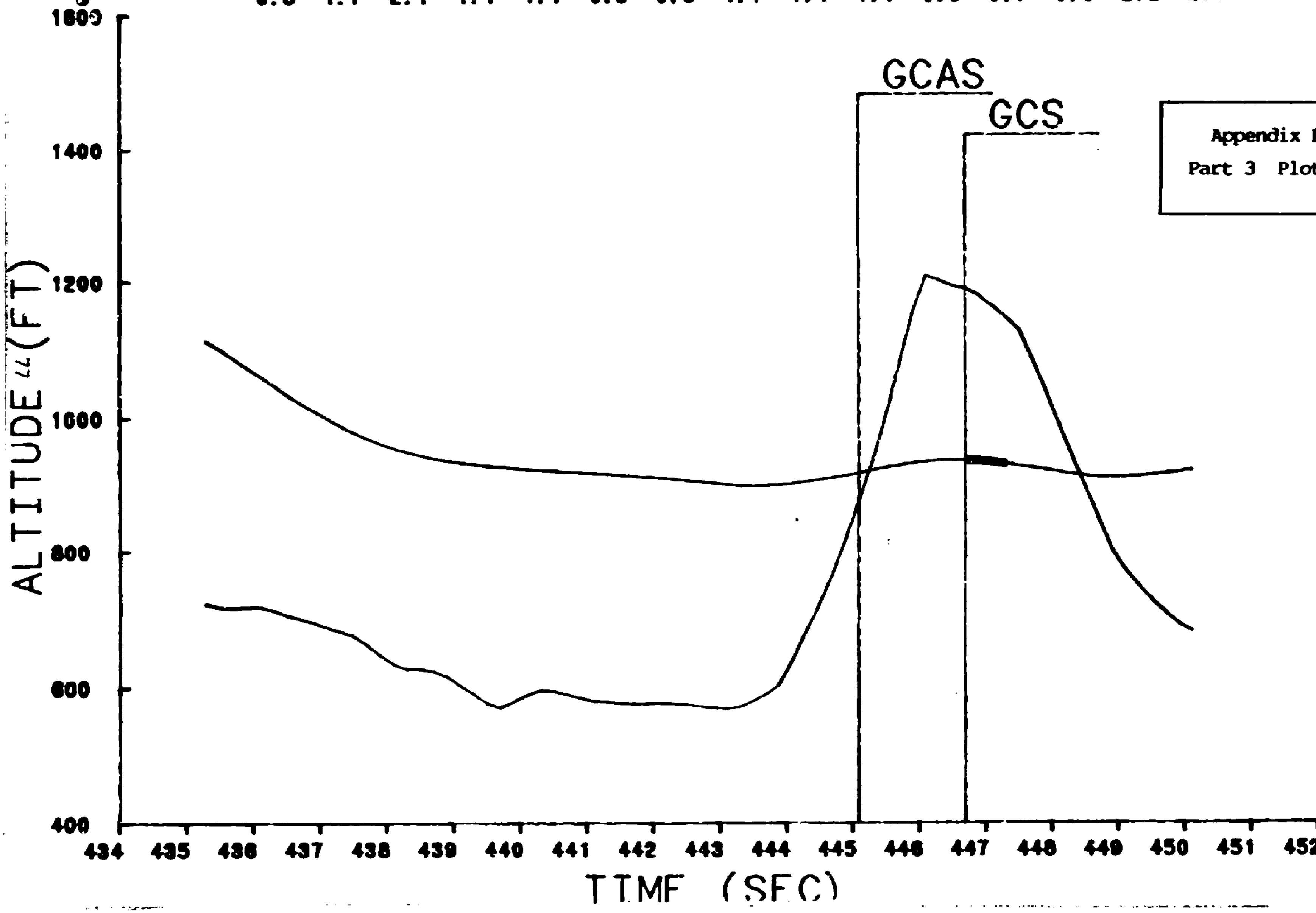
CAS	893	895	898	901	903	905	906	909	905	899	887	877	868	860	855
FPA	2	0	−1	−1	1	1	0	−2	−2	0	1	3	2	1	1
ROLL	1	1	1	1	1	1	−4	−10	−11	−20	−26	−28	−34	−38	−42
G	0.2	0.1	0.6	1.7	1.8	1.1	0.1	0.4	1.5	1.6	2.4	1.5	0.5	0.8	1.2



GCS MISSION 17 SUBJECT 1

EVENT #4

CAS	822	826	836	842	845	844	841	838	834	832	827	824	822	818	814
FPA	-5	-4	-2	-1	-1	0	-1	-1	1	1	1	-1	-1	0	1
ROLL	-7	-24	-17	-6	-2	6	5	5	4	4	4	4	30	46	61
G	0.8	1.7	2.1	1.4	1.1	0.9	0.8	1.1	1.4	1.1	0.5	0.7	0.8	2.2	2.8

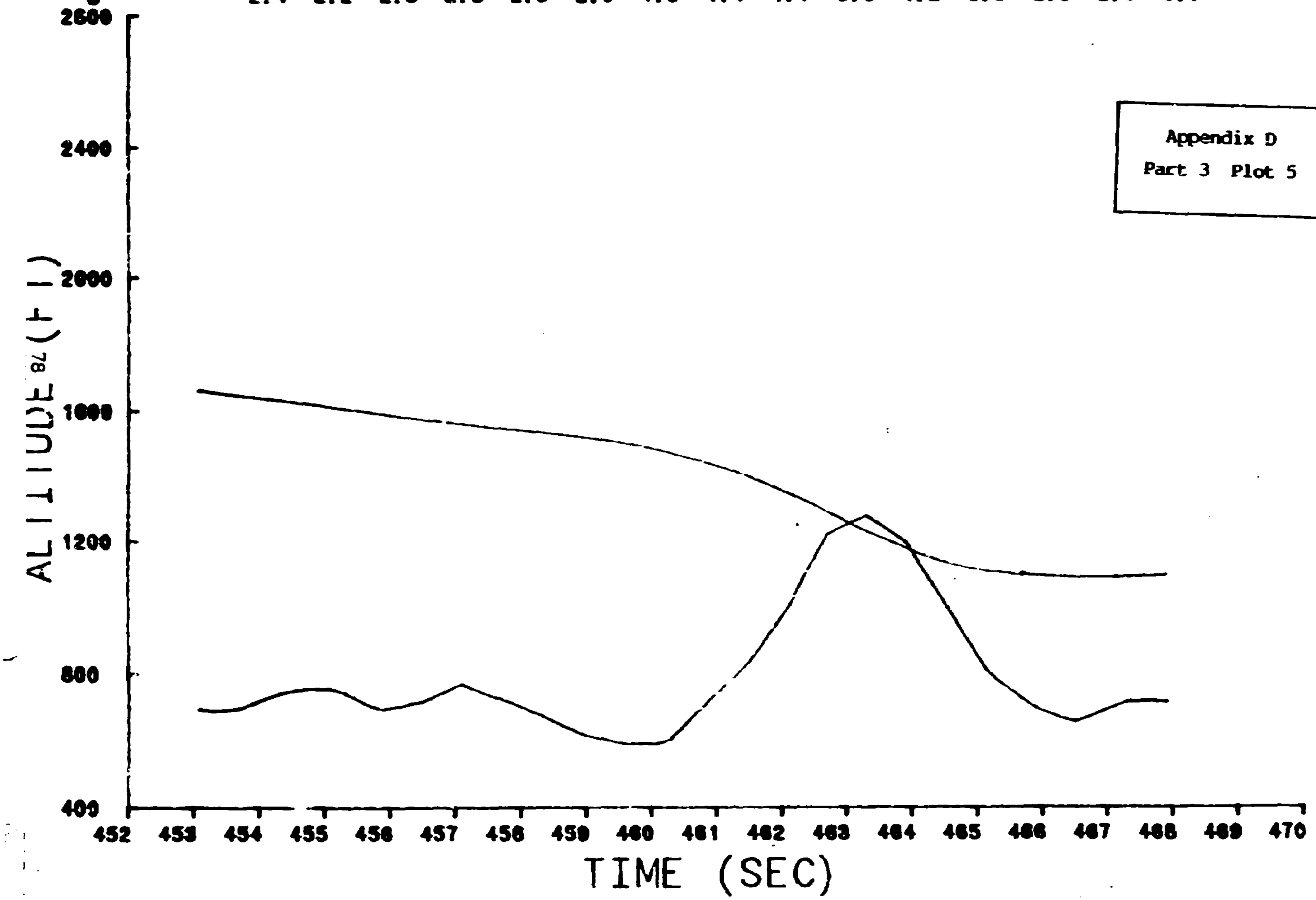


Appendix D
Part 3 Plot 4

GCS MISSION 17 SUBJECT 2

EVENT #1

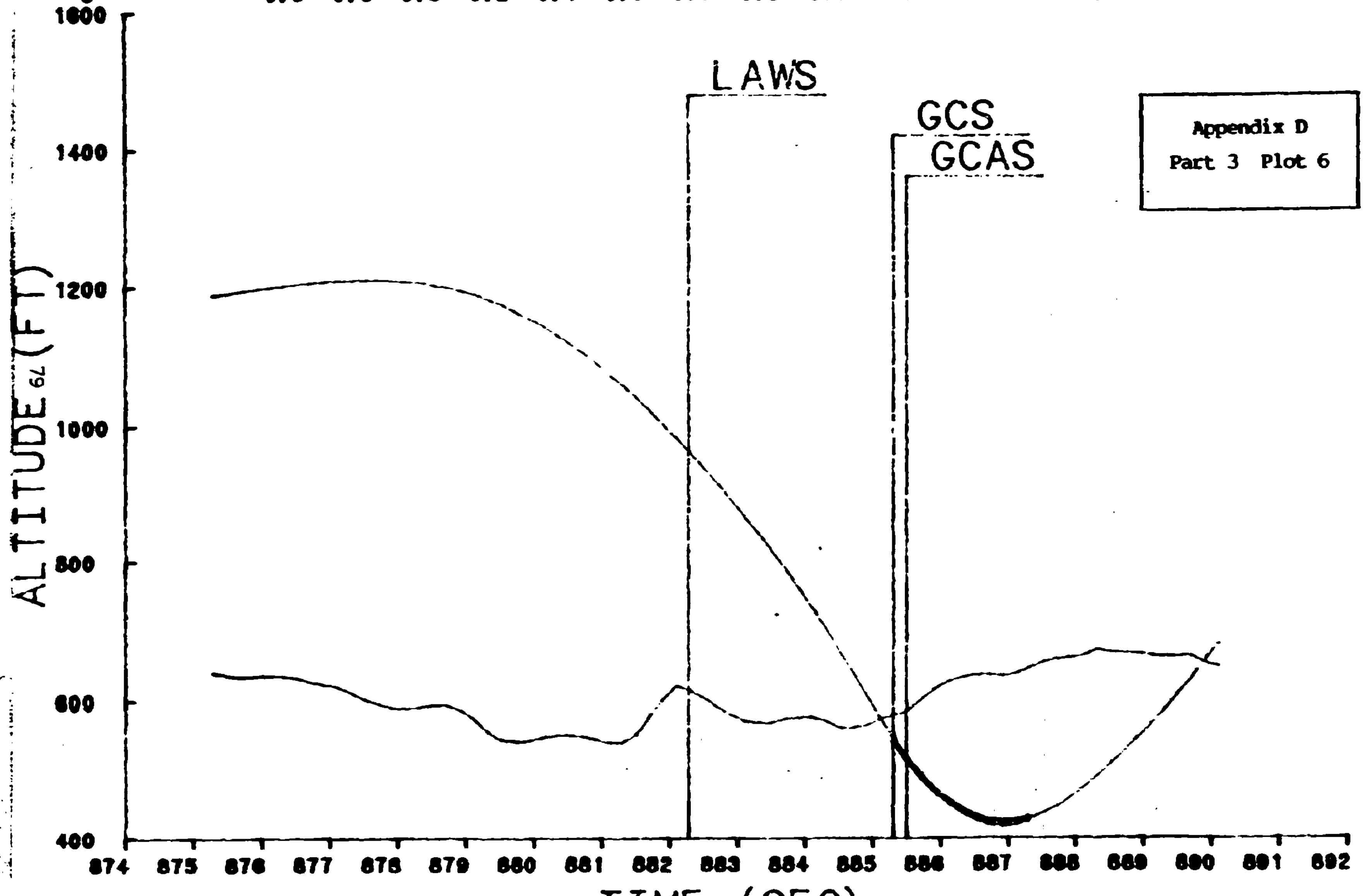
CAS	917	918	918	919	919	919	921	923	926	929	927	922	921	920	918
FPA	-2	-2	-2	-2	-1	-2	-3	-4	-5	-6	-5	-2	-1	0	1
ROLL	64	66	66	66	65	68	75	76	79	71	65	57	57	60	71
G	2.4	2.2	2.5	2.8	2.5	2.0	1.5	1.4	1.1	3.6	4.2	3.5	2.8	2.6	3.0



GCS MISSION 17 SUBJECT 2

EVENT #2

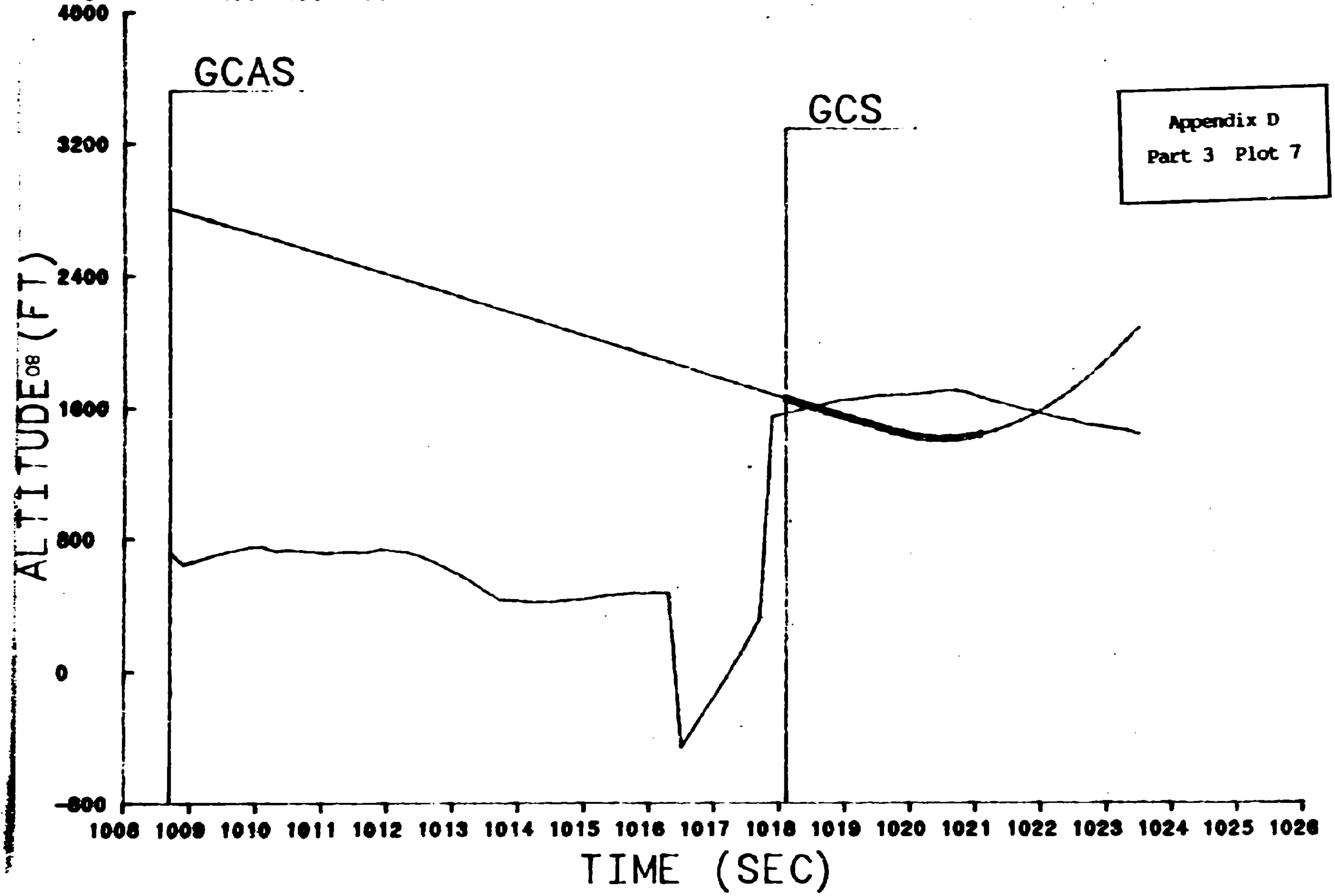
CAS	923	924	925	927	929	931	936	940	944	949	949	934	917	910	901
FPA	1	0	−1	−2	−4	−5	−6	−8	−9	−10	−5	1	5	7	8
ROLL	1	−4	−23	−45	−58	−66	−66	−66	−68	−60	46	61	65	67	33
G	0.9	0.3	0.5	0.2	0.4	0.5	0.8	0.9	0.9	1.2	5.2	7.7	6.5	3.9	2.7



GCS MISSION 17 SUBJECT 2

EVENT #3

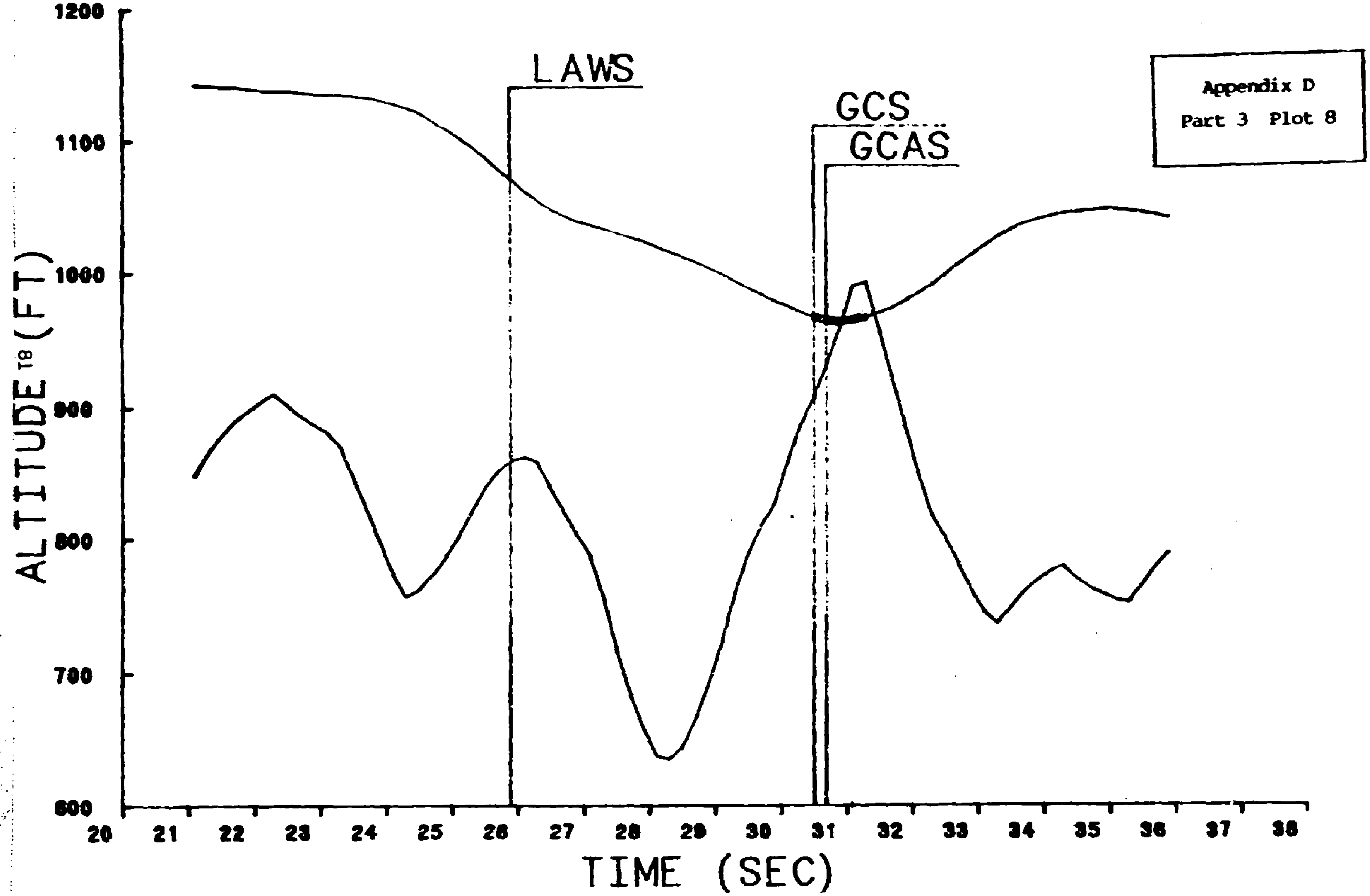
CAS	948	949	953	956	959	962	964	967	969	971	973	965	947	927	913
FPA	-7	-7	-7	-7	-7	-7	-7	-7	-7	-7	-7	-1	9	19	27
ROLL	-2	0	0	0	0	0	-1	-1	-1	-1	-1	-13	-9	-11	-9
G	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.8	6.6	5.9	6.3	2.5



GCS MISSION 17 SUBJECT 3

EVENT #1

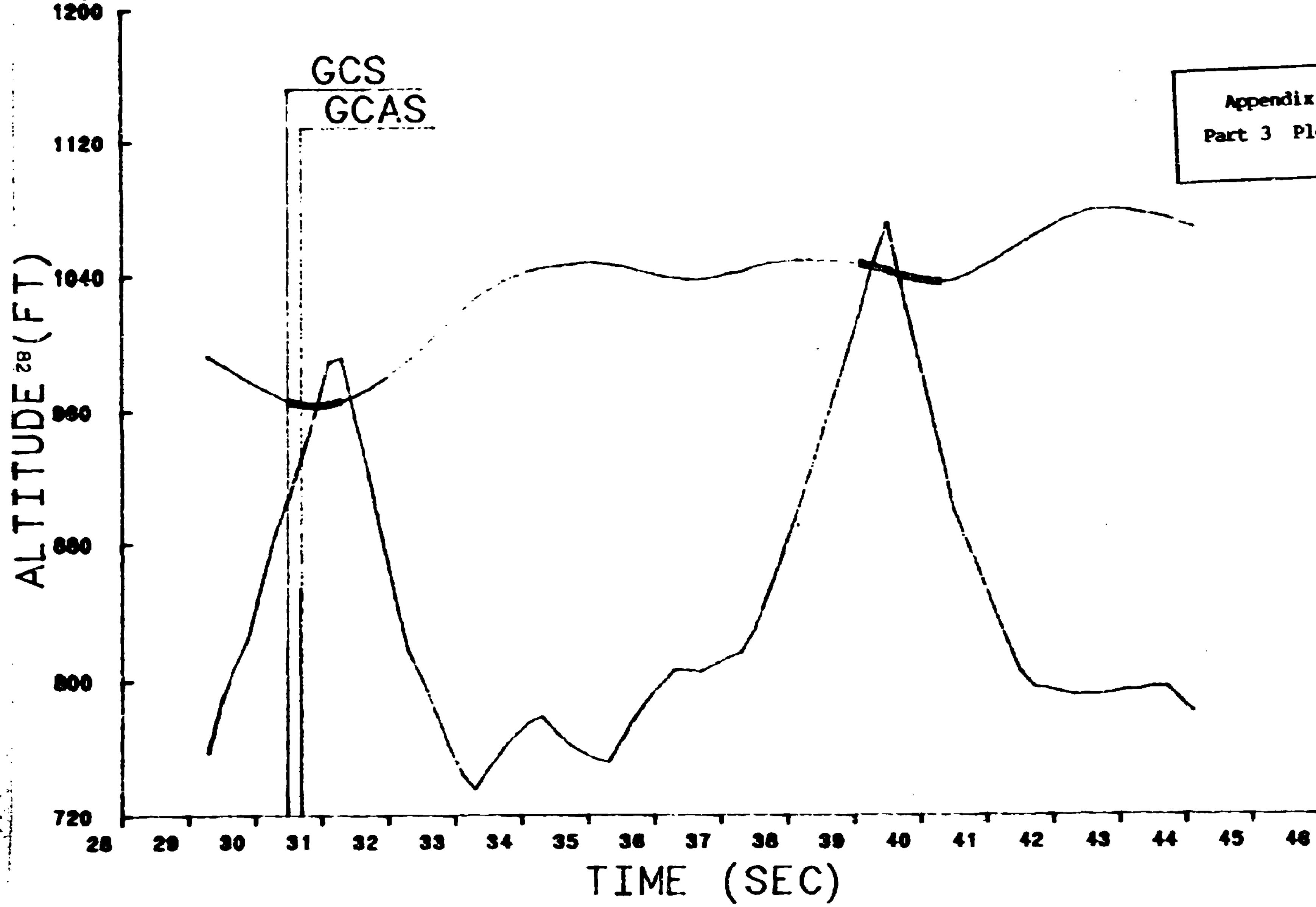
CAS	717	713	711	709	708	706	704	703	702	699	695	691	687	685	684
FPA	0	0	−1	−3	−4	−2	−1	−2	−2	0	2	3	1	0	−1
ROLL	0	0	−1	−1	−1	0	1	2	2	3	3	3	3	3	3
G	1.0	1.0	0.5	0.3	1.1	1.8	0.8	0.8	1.2	2.2	1.6	1.4	0.4	0.5	0.8



GCS MISSION 17 SUBJECT 3

EVENT #2

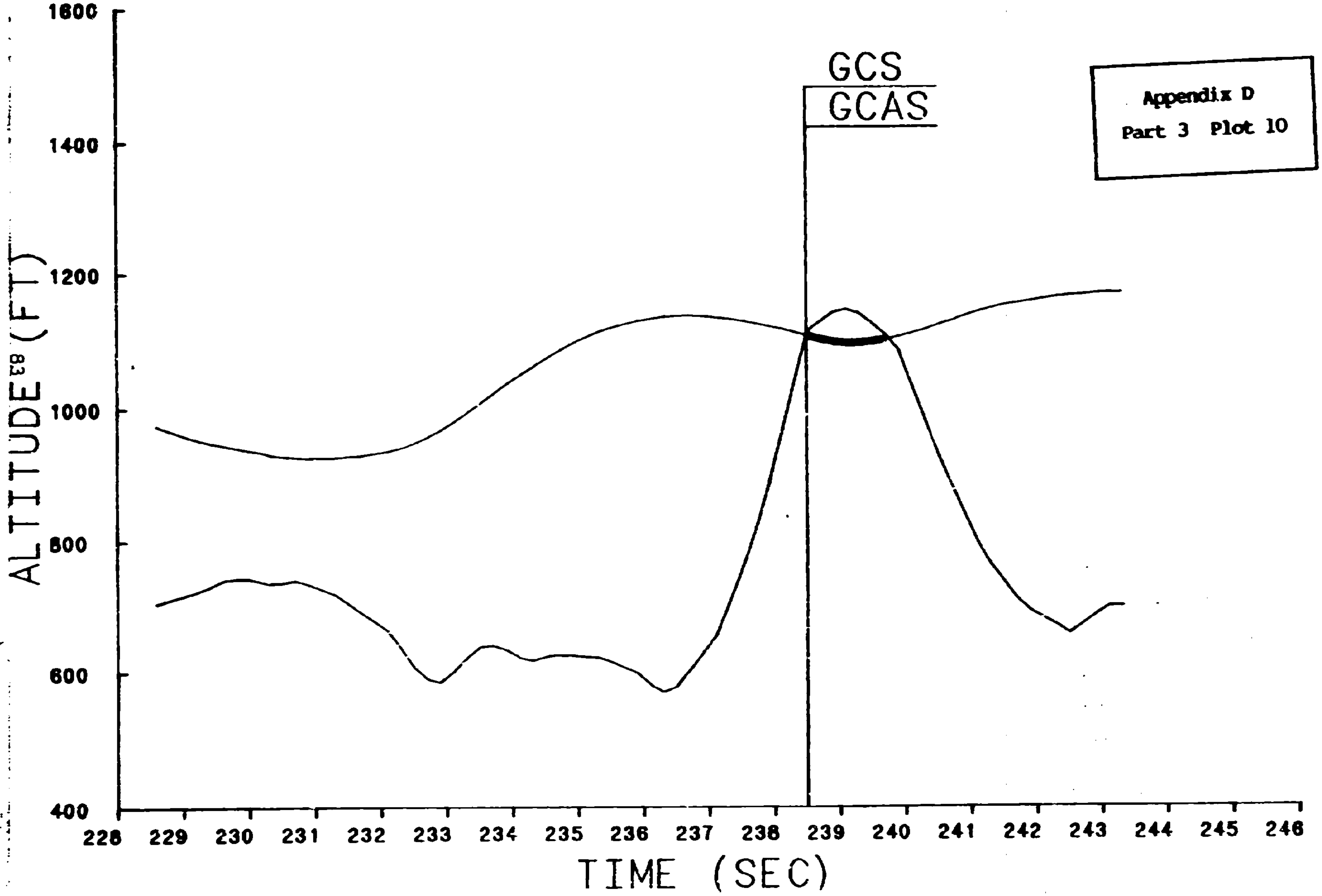
CAS	701	698	694	691	687	685	684	681	679	677	676	674	670	668	667
FPA	−2	1	2	3	1	0	−1	1	0	−1	−1	2	2	0	−1
ROLL	1	3	3	3	3	3	3	4	1	−1	−1	0	0	0	−2
G	1.3	2.2	1.6	0.5	0.5	0.5	0.8	1.5	0.6	0.7	1.8	1.3	0.5	0.4	0.8



GCS MISSION 17 SUBJECT 4

EVENT #1

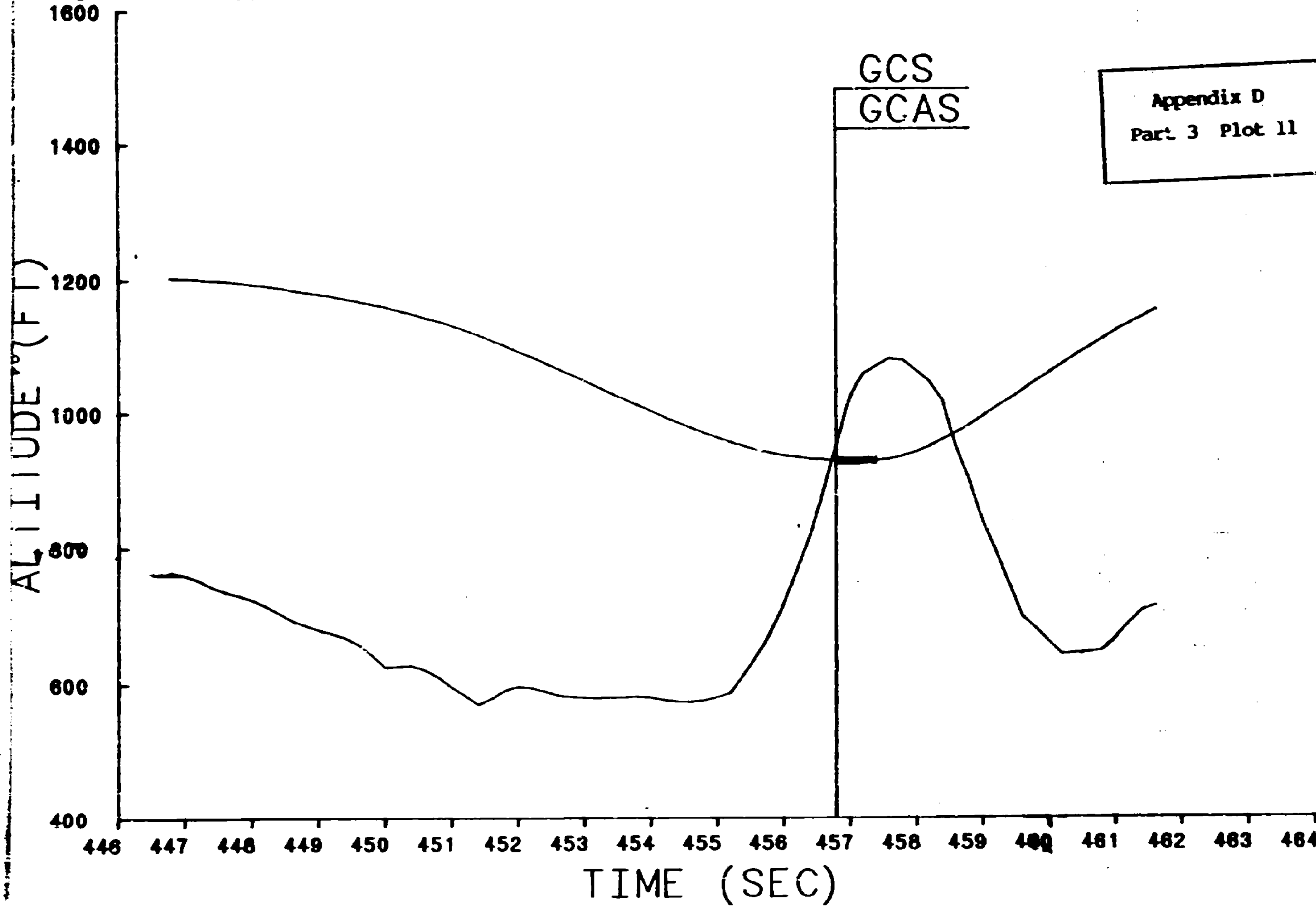
CAS	912	913	914	914	911	908	900	900	902	904	905	905	908	906	907
FPA	-2	-1	0	2	4	4	2	1	-1	-2	0	2	2	1	0
ROLL	-56	-43	-25	4	58	83	91	68	53	33	28	28	29	33	42
G	1.4	2.0	1.7	2.2	3.4	5.0	2.6	0.4	0.3	1.1	3.6	1.9	0.3	0.9	1.0



GCS MISSION 17 SUBJECT 4

EVENT #2

CAS	925	924	923	923	923	923	923	922	922	921	920	915	913	909	907
FPA	-1	-1	-1	-2	-3	-3	-3	-3	-2	-1	1	4	4	4	3
ROLL	59	59	60	61	66	62	60	-17	0	25	37	44	47	57	64
G	1.5	2.0	1.5	1.4	1.6	1.8	2.3	1.5	1.7	1.5	2.0	2.6	1.5	1.2	1.3

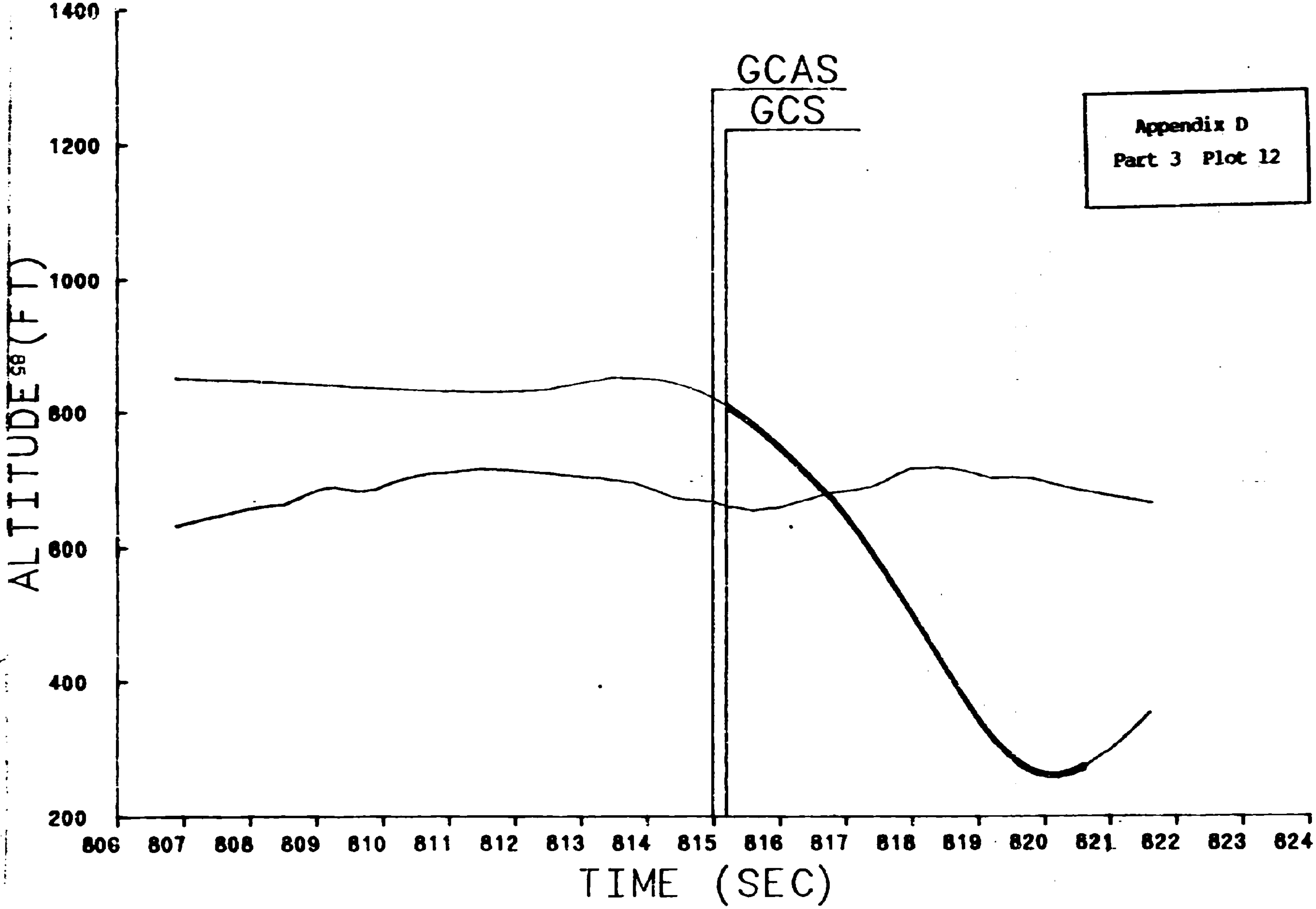


Appendix D
Part 3 Plot 11

GCS MISSION 17 SUBJECT 4

EVENT #3

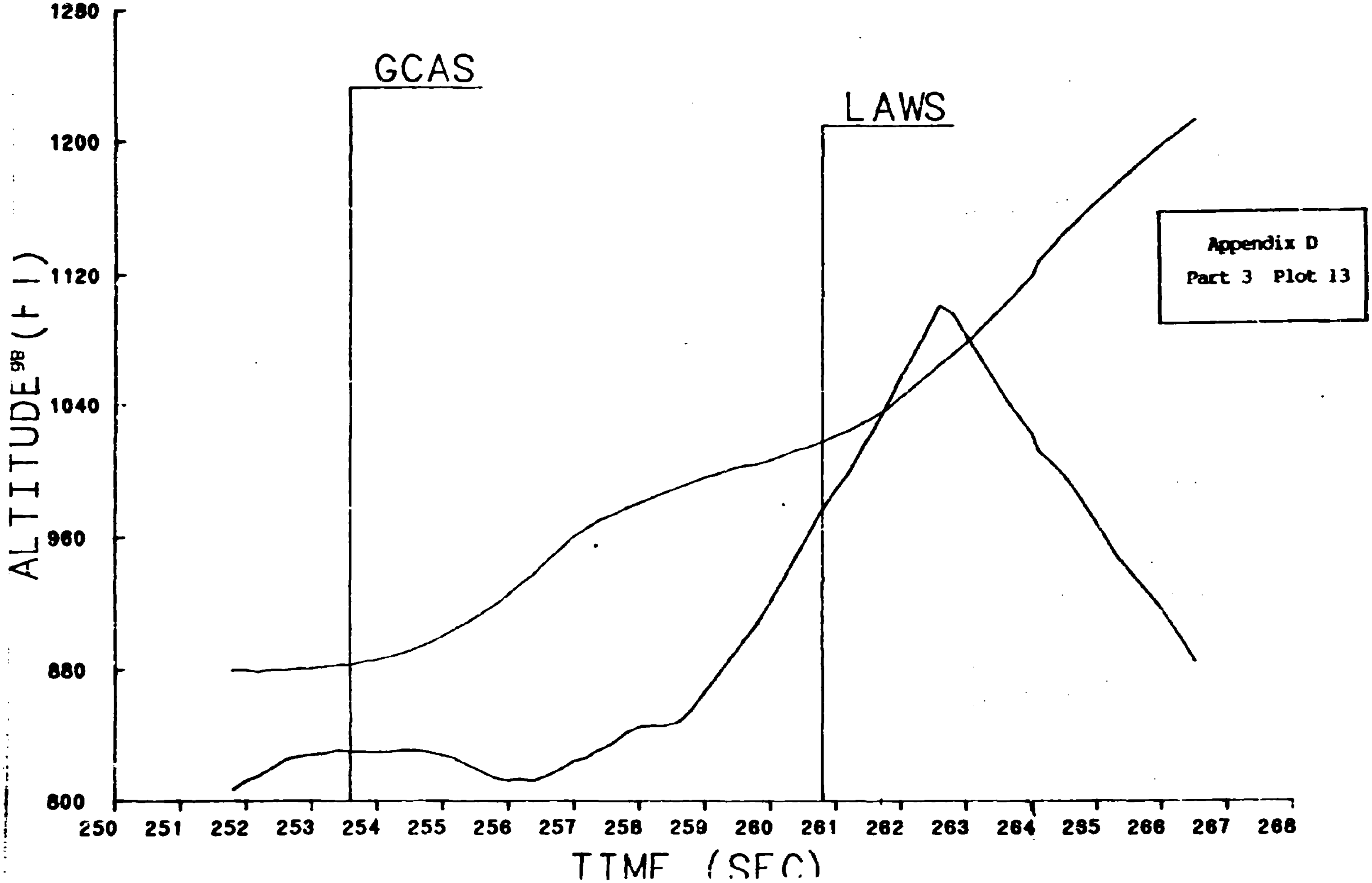
CAS	953	952	952	952	951	951	950	950	950	953	956	960	958	953	945
FPA	0	0	0	0	0	1	0	−2	−5	−6	−9	−10	−4	3	6
ROLL	1	1	0	−1	−3	−3	−2	−1	−1	0	1	1	0	−1	−1
G	1.0	1.0	1.0	1.1	1.2	1.7	−0.4	−0.6	−0.3	−0.4	0.2	0.6	4.9	3.6	1.9



GCS MISSION 17 SUBJECT 6

EVENT #1

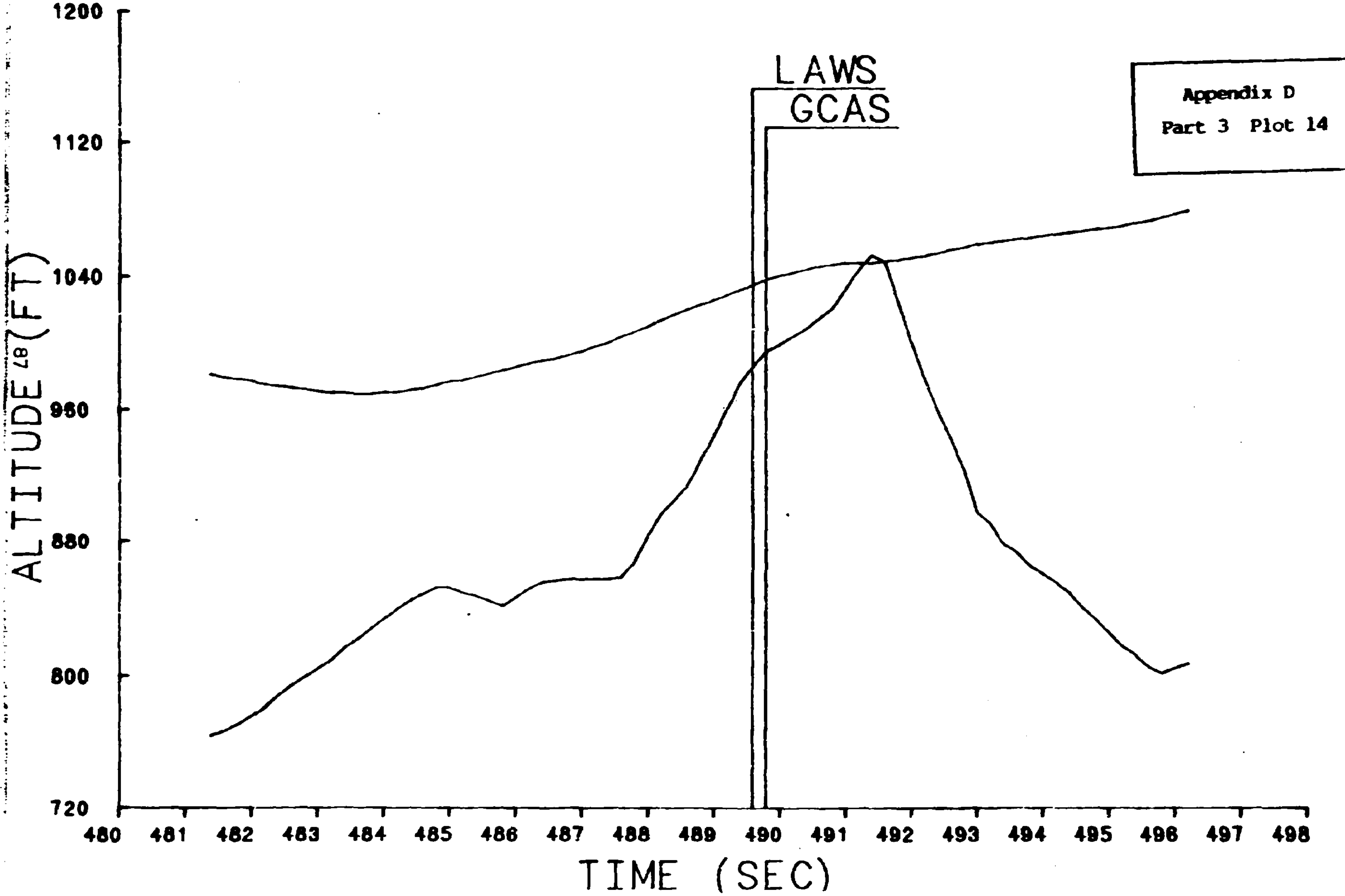
CAS	755	757	758	759	759	759	760	761	762	762	761	760	760	760	760
FPA	0	0	1	2	3	1	1	1	1	2	3	3	3	3	2
ROLL	-10	-2	4	8	5	-9	-7	42	44	44	46	46	49	56	56
G	1.1	1.2	1.5	1.3	1.1	0.7	0.9	1.1	1.5	2.1	1.5	1.7	1.4	1.5	1.8



GCS MISSION 17 SUBJECT 6

EVENT #2

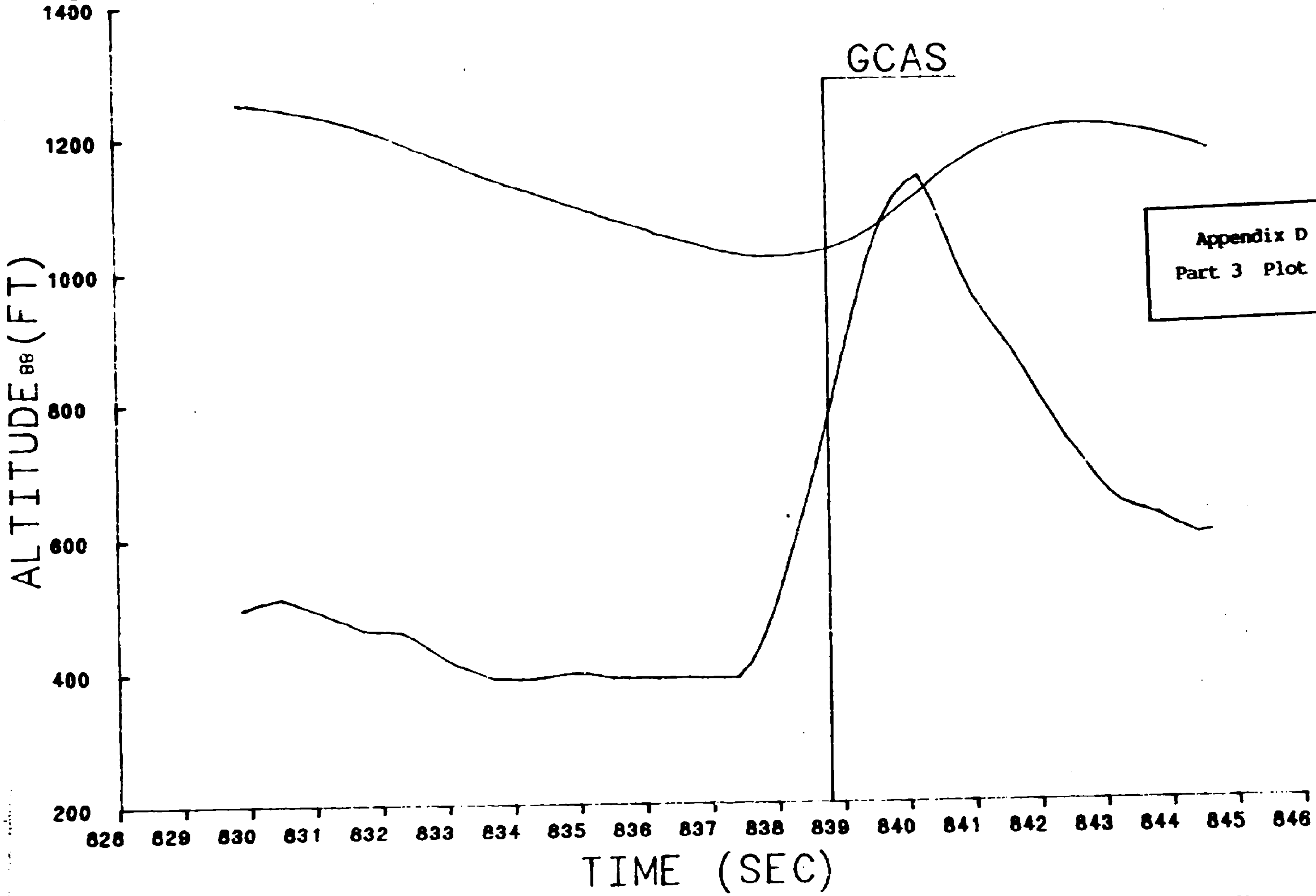
CAS	670	668	666	664	662	659	657	654	652	651	648	646	644	641	638
FPA	-1	0	0	1	1	1	1	1	1	0	1	1	0	1	1
ROLL	3	3	1	0	0	-4	-12	7	36	43	42	50	49	53	56
G	1.0	1.1	1.3	1.1	0.9	1.4	1.0	1.0	0.-	1.1	1.5	1.4	1.6	1.8	1.7



GCS MISSION 17 SUBJECT 6

EVENT #3

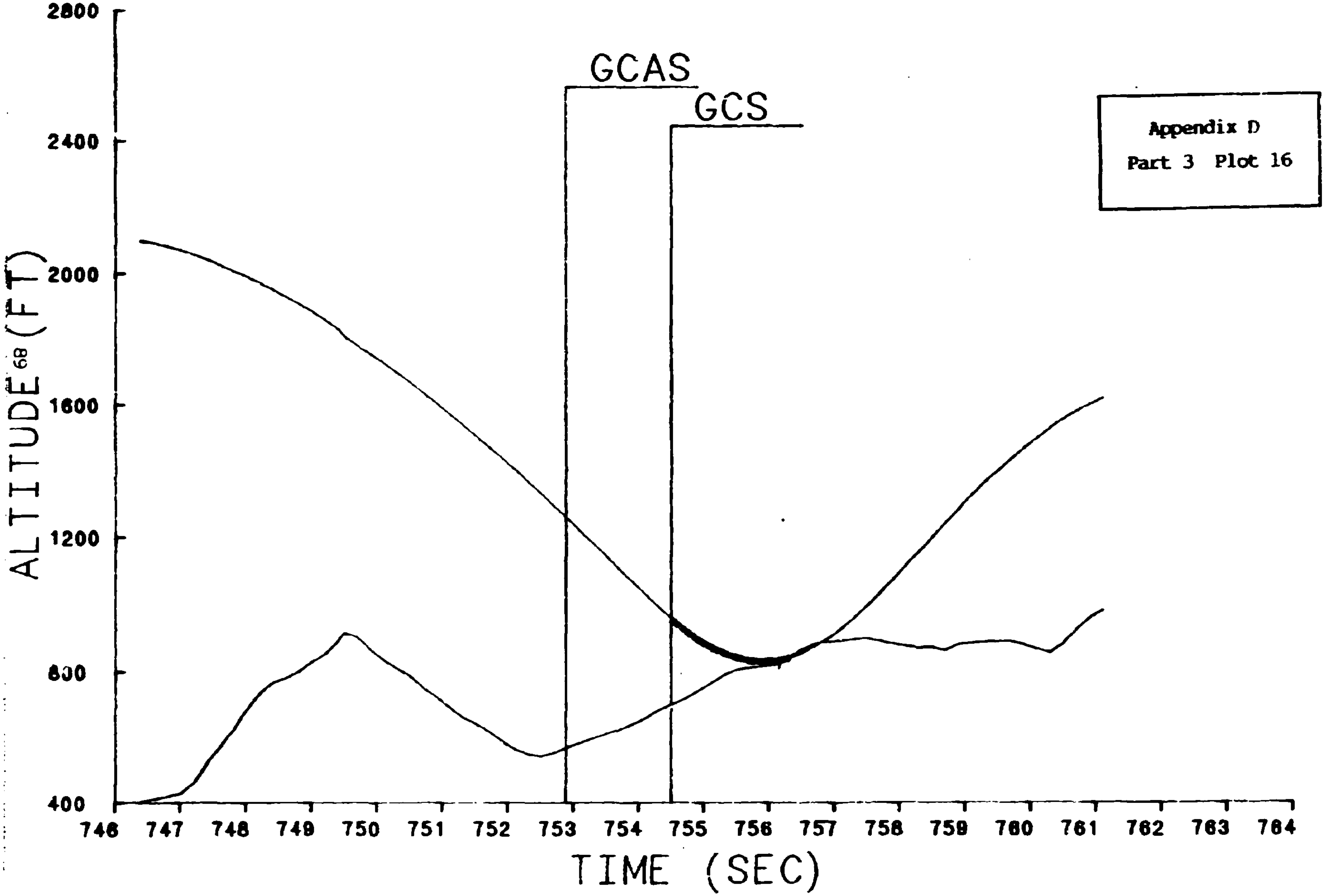
CAS	889	892	894	896	898	900	901	902	904	904	903	900	902	905	908
FPA	-1	-2	-3	-2	-2	-2	-2	-1	1	4	5	2	0	-1	-3
ROLL	76	77	76	67	71	70	71	38	14	-7	22	78	77	64	47
G	2.5	2.4	3.2	3.6	2.9	3.2	3.2	2.5	1.6	2.1	-0.2	-1.0	0.6	0.9	0.0



GCS MISSION 17 SUBJECT 8

EVENT #1

CAS	790	800	810	821	831	841	852	859	858	849	835	830	827	824	820
FPA	−5	−7	−9	−10	−11	−12	−13	−13	−7	2	11	15	14	11	7
ROLL	93	83	80	78	76	75	71	63	−16	−17	−7	1	9	12	15
G	1.6	1.5	1.6	2.0	2.4	2.5	2.7	3.3	4.8	6.3	4.0	1.7	−0.1	−0.4	−0.2

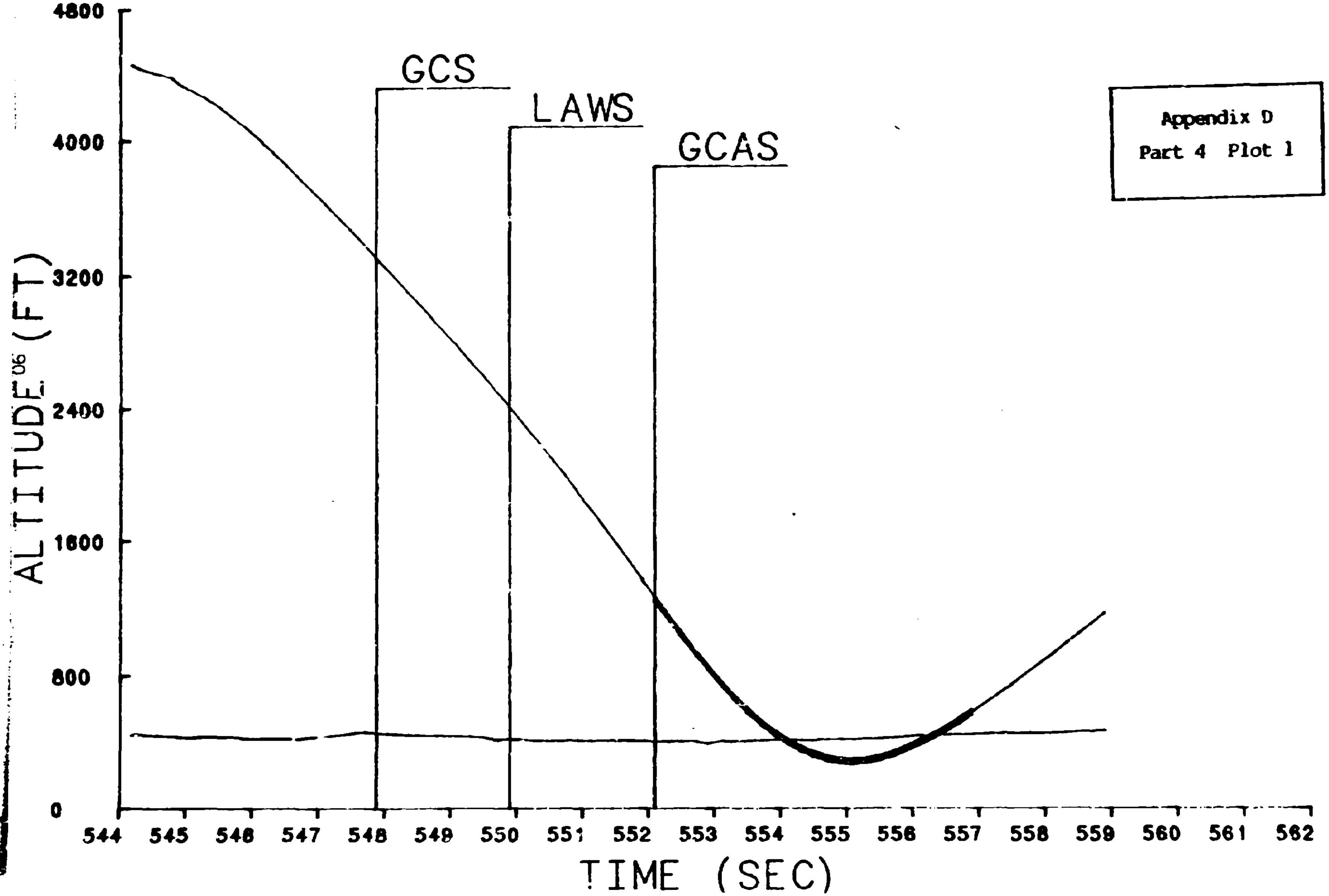


Appendix D
Part 3 Plot 16

GCAS MISSION 15 SUBJECT 1

EVENT #1

CAS	670	683	706	731	746	778	803	823	847	844	823	781	784	775	770
FPA	−18	−28	−34	−35	−36	−38	−40	−41	−34	−20	−4	12	19	22	24
ROLL	178	177	−49	−72	−123	−58	−97	−34	−15	7	8	7	4	−2	−3
G	3.6	2.9	2.0	0.1	−0.6	−0.6	0.4	0.7	6.4	8.1	3.7	5.6	3.2	1.7	1.4



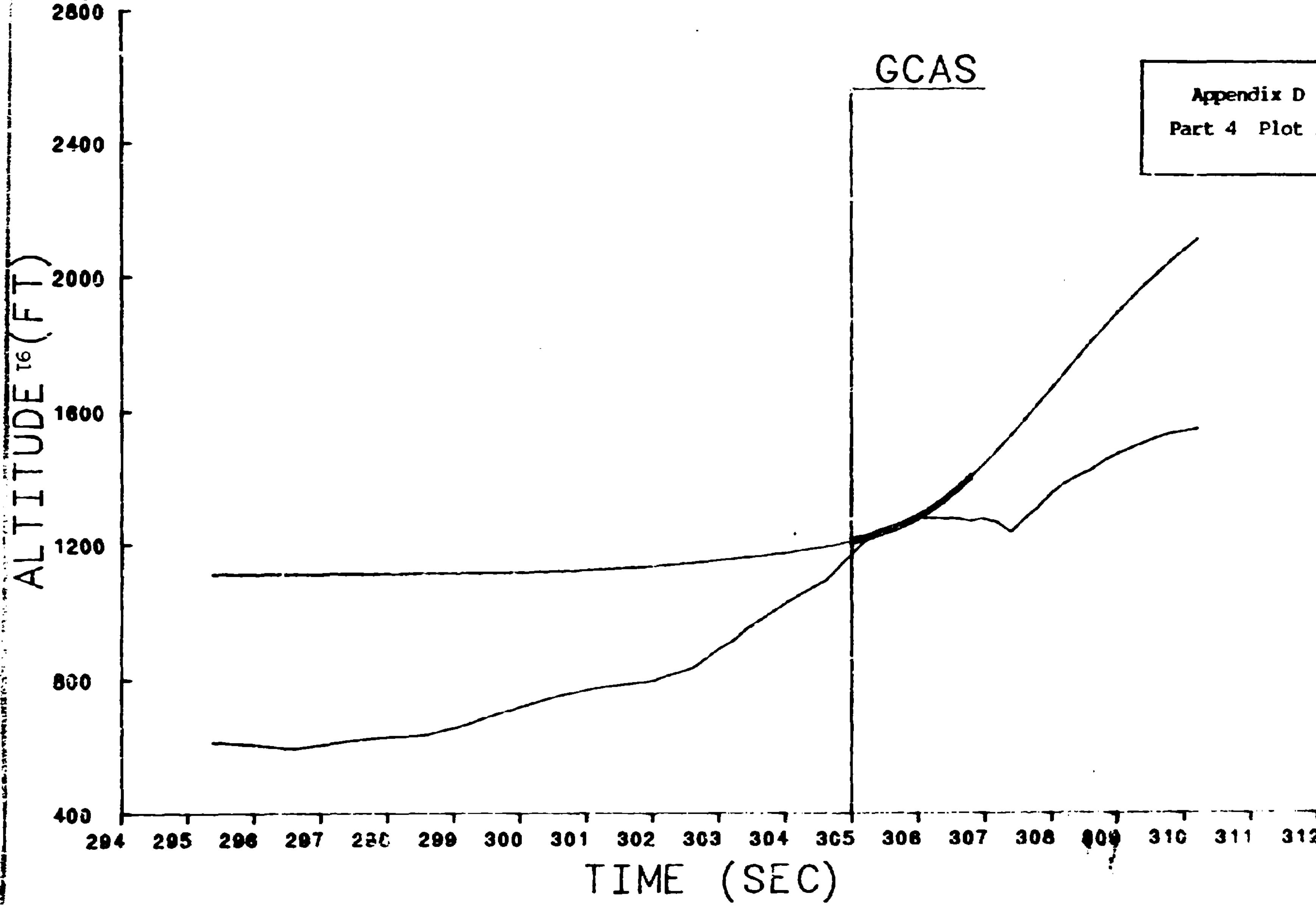
Appendix D

Part 4 Plot 1

GCAS MISSION 15 SUBJEC! 2

EVENT #1

CAS	839	838	838	838	838	837	837	836	835	833	831	815	806	800	791
FPA	0	0	0	0	0	1	1	1	2	4	9	15	17	14	12
ROLL	−4	−6	−8	−9	−7	6	7	7	7	7	3	1	0	1	1
G	1.1	1.0	1.0	1.0	1.1	1.2	1.2	1.1	1.3	2.1	4.5	2.8	0.9	−0.3	0.3

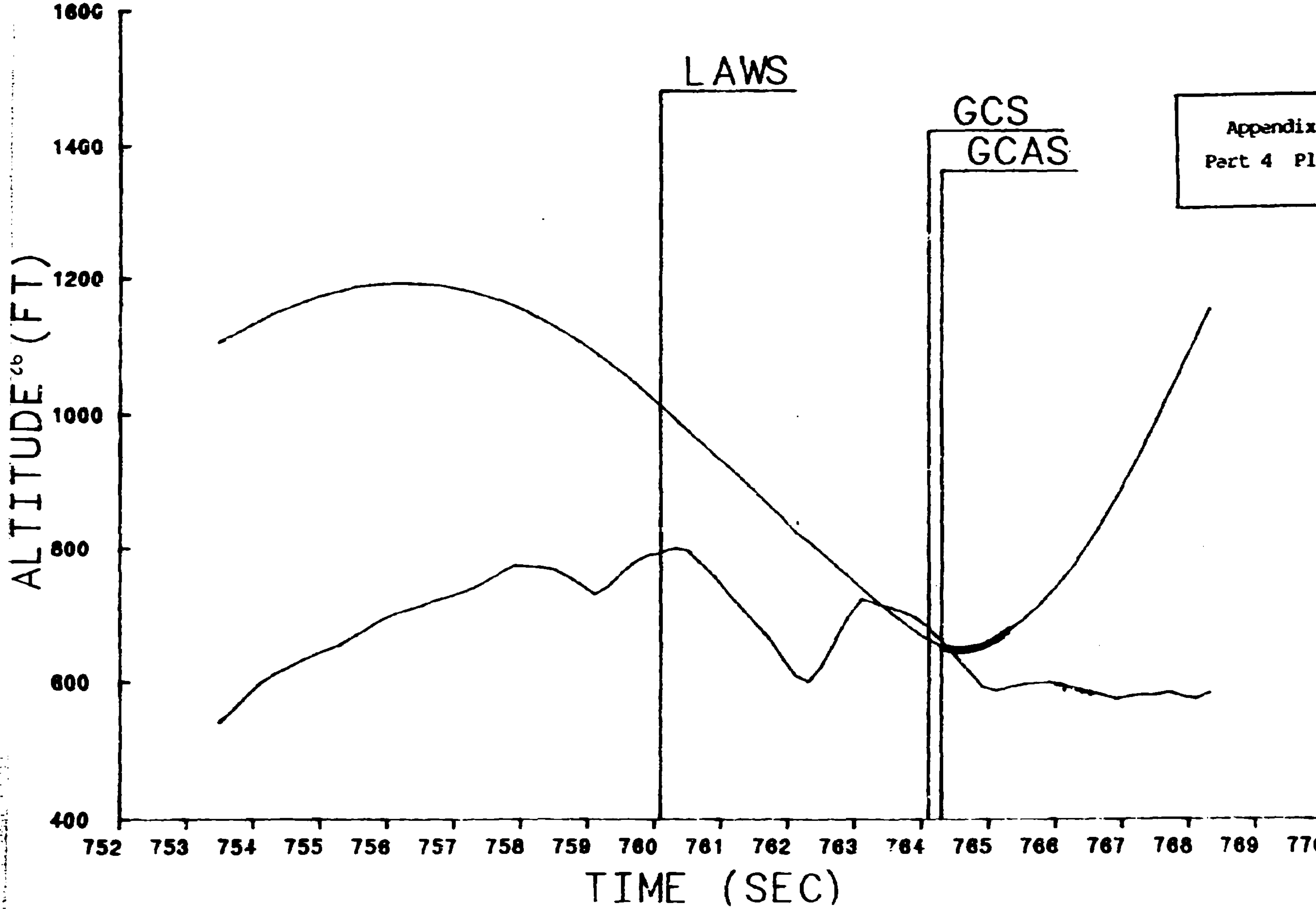


Appendix D
Part 4 Plot 2

GCAS MISSION 15 SUBJECT 2

EVENT #2

CAS	891	890	890	891	892	896	898	900	901	901	897	886	884	874	867
FPA	3	2	C	−2	−3	−5	−6	−6	−6	−5	−3	4	9	13	14
ROLL	−63	−75	−76	−76	−76	−73	−72	−72	−70	−69	−42	−27	−7	3	12
G	1.0	1.0	0.9	0.−	1.0	1.2	2.7	2.5	3.6	5.3	4.3	3.4	4.1	2.1	0.9

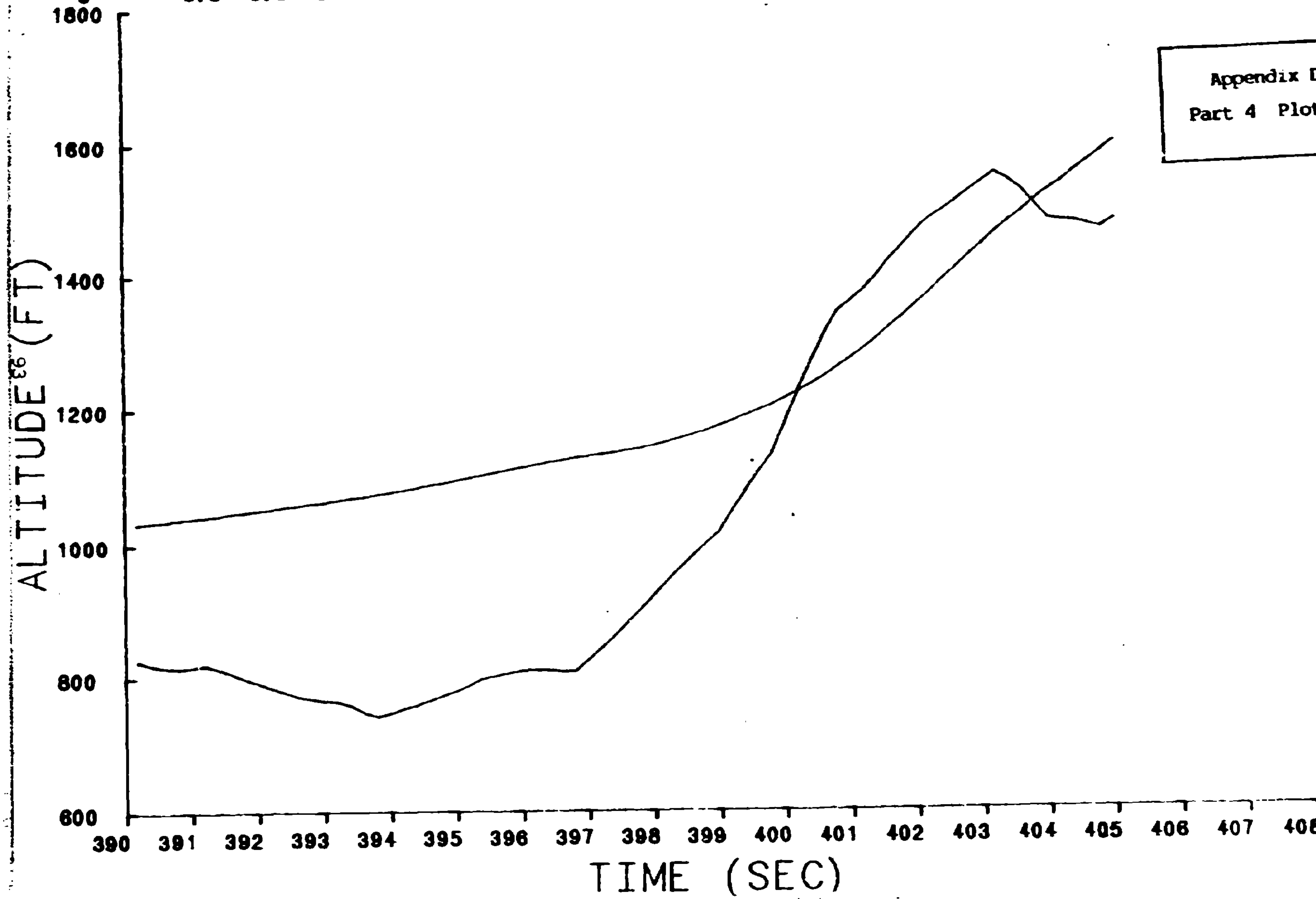


Appendix D
Part 4 Plot 3

GCAS MISSION 15 SUBJECT 3

EVENT #1

CAS	831	826	823	819	812	803	794	785	779	767	759	752	746	745	745
FPA	1	1	1	1	1	1	1	1	3	3	5	7	7	6	6
ROLL	-71	-72	-73	-74	-76	-80	-80	-72	-74	-69	-67	-68	-79	-56	-7
G	3.3	3.3	3.5	3.8	4.4	4.8	4.9	4.8	4.5	4.4	4.3	3.9	2.7	1.5	1.0



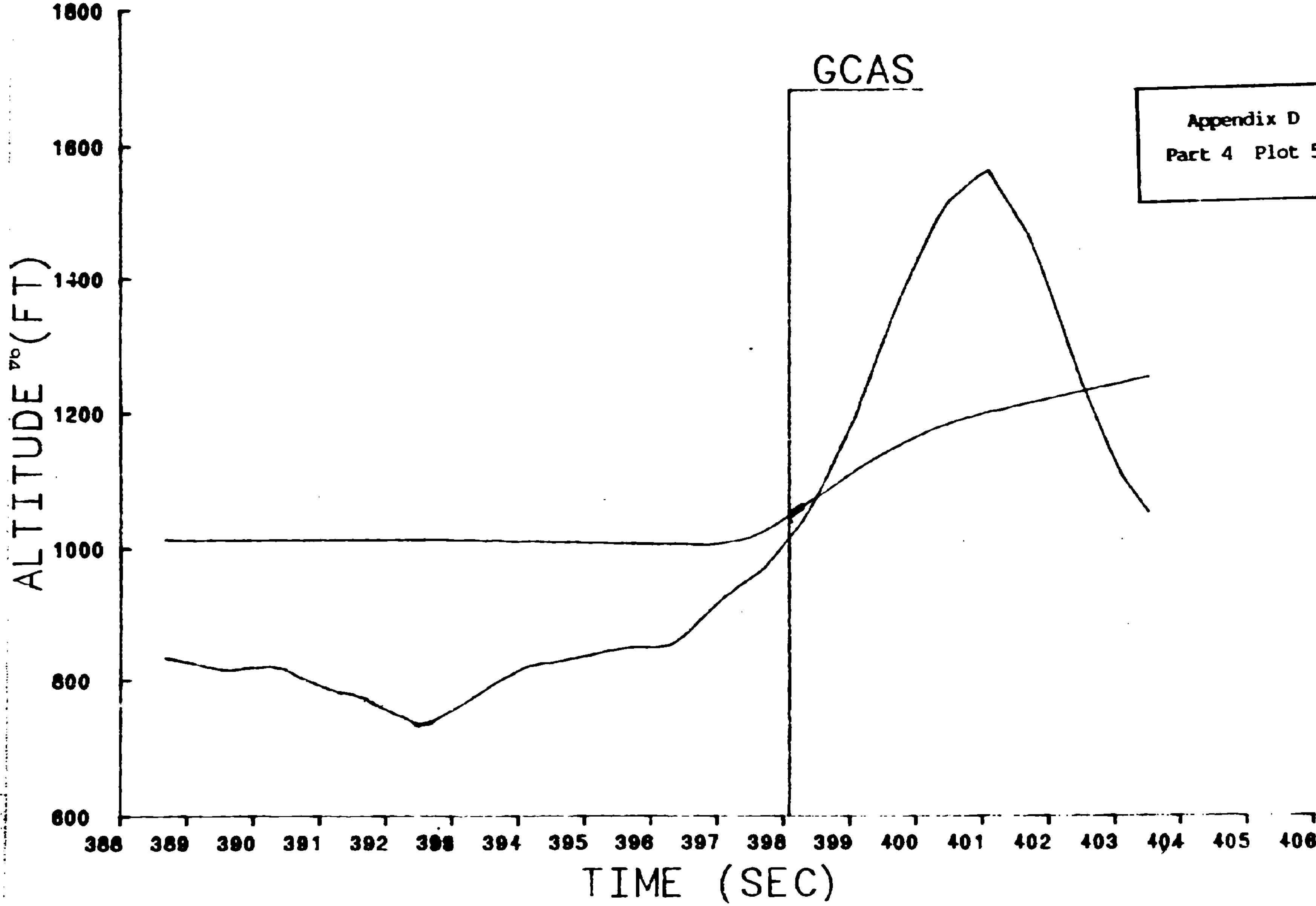
Appendix D

Part 4 Plot 4

GCAS MISSION 15 SUBJECT 6

EVENT #1

CAS	849	851	852	853	854	855	855	855	852	848	847	847	848	849	849
FPA	0	0	0	0	0	0	0	0	2	5	4	2	1	2	1
ROLL	-64	-66	-66	-69	-67	-68	-71	-71	-48	-65	-81	-79	-70	-64	-63
G	2.2	2.3	2.6	2.5	2.5	2.8	3.0	3.1	4.9	2.8	1.9	1.9	2.5	2.0	1.8

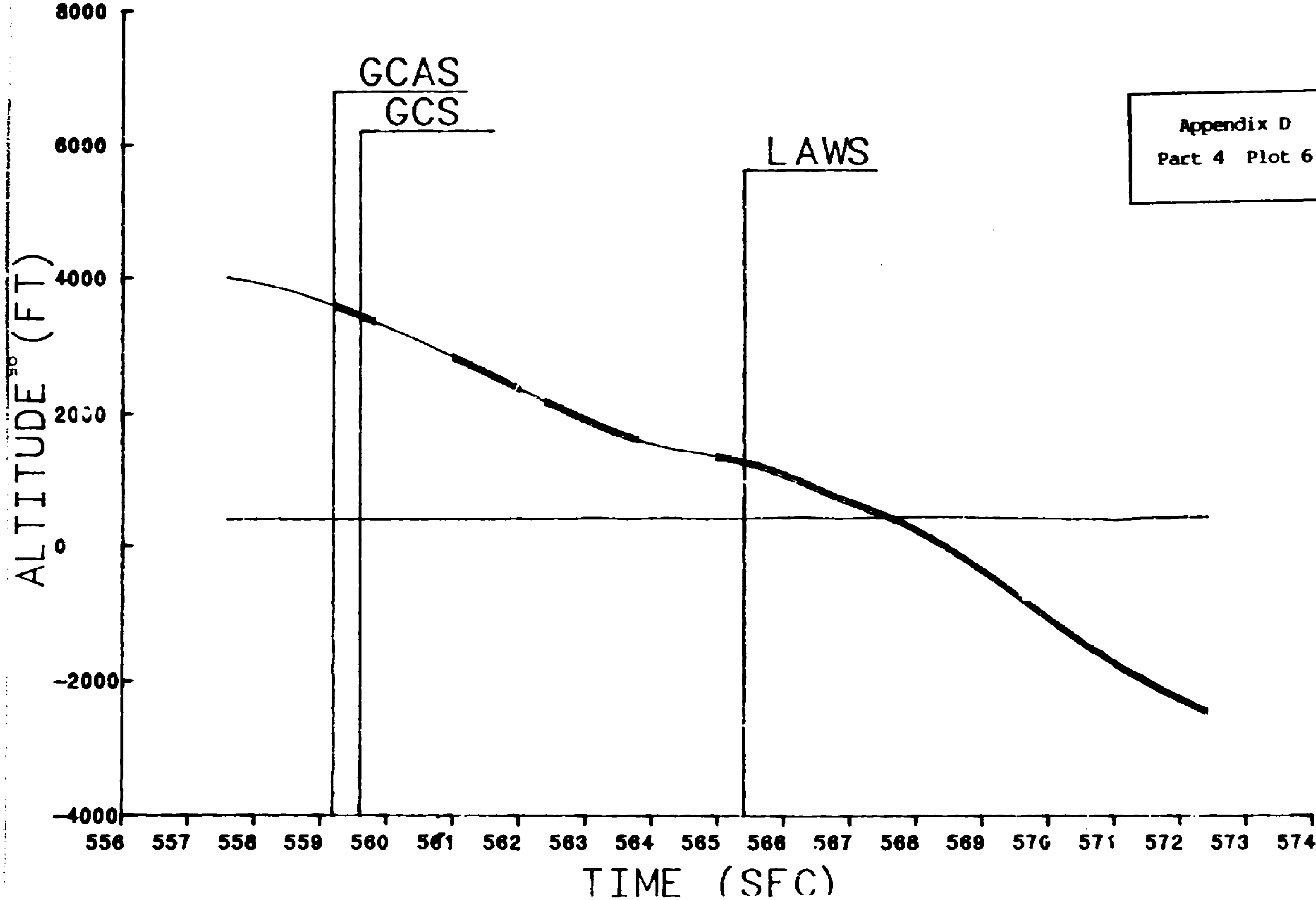


Appendix D
Part 4 Plot 5

GCAS MISSION 15 SUBJECT 6

EVENT #2

CAS	742	757	778	800	822	836	821	812	805	802	780	733	732	713	723
FPA	-20	-30	-34	-36	-35	-27	-13	-17	-34	-30	-51	-75	-69	-51	-39
ROLL	176	174	31	18	4	1	15	180	103	-139	174	60	20	11	7
G	3.3	3.0	0.4	0.-	1.7	6.9	8.3	5.4	7.8	4.1	10.2	8.9	9.0	7.9	5.1

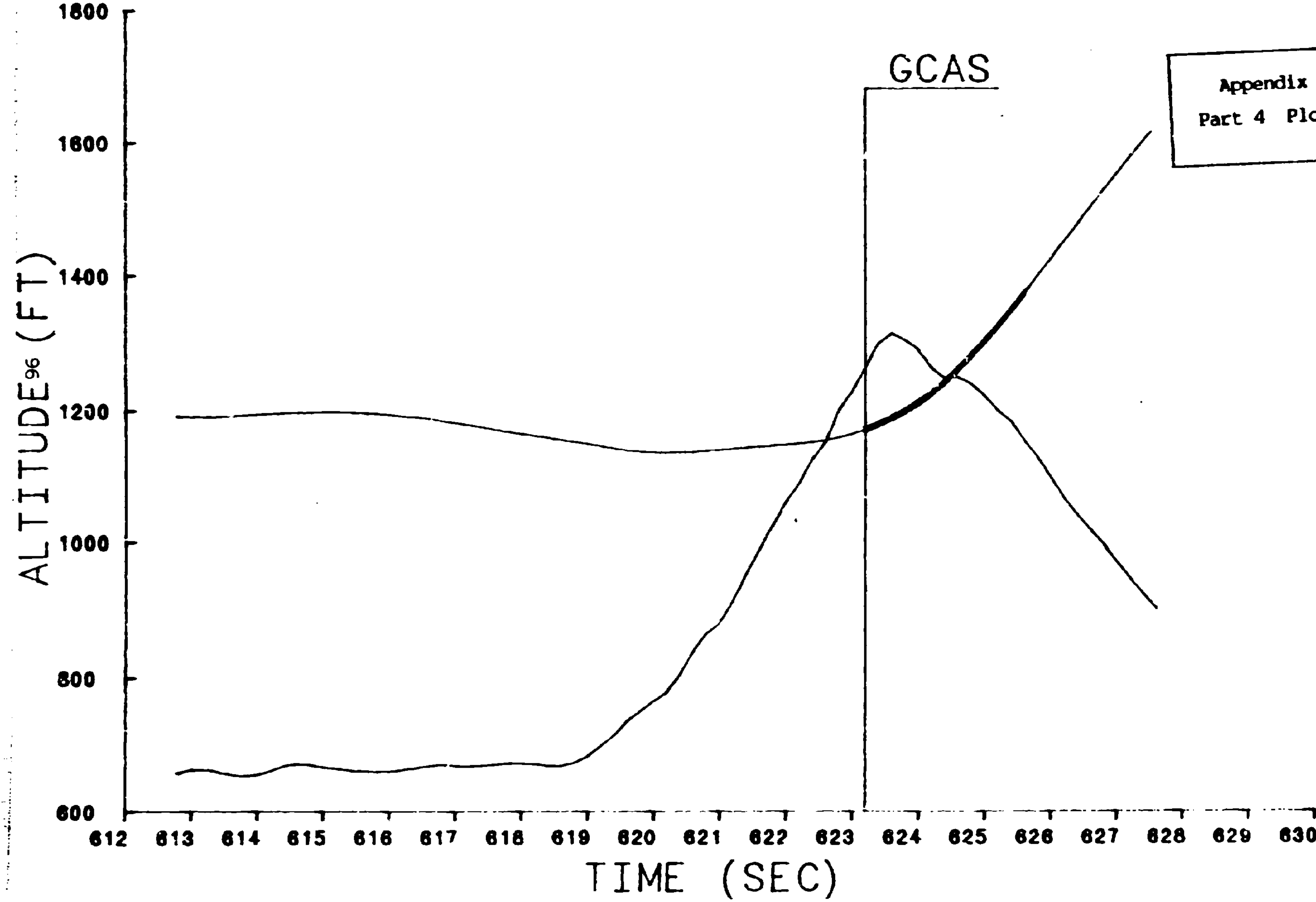


Appendix D
Part 4 Plot 6

GCAS MISSION 15 SUBJECT 6

EVENT #3

CAS	893	894	894	895	896	897	898	896	895	893	888	879	874	871	868
FPA	0	0	0	−1	−1	−1	−1	0	0	1	3	7	8	9	8
ROLL	−44	−47	−54	−51	−48	−47	−51	−62	−70	−62	−58	−53	−48	−55	−69
G	1.7	1.2	1.1	1.2	1.9	1.3	2.7	3.1	2.6	3.5	3.8	3.4	2.1	1.4	1.0

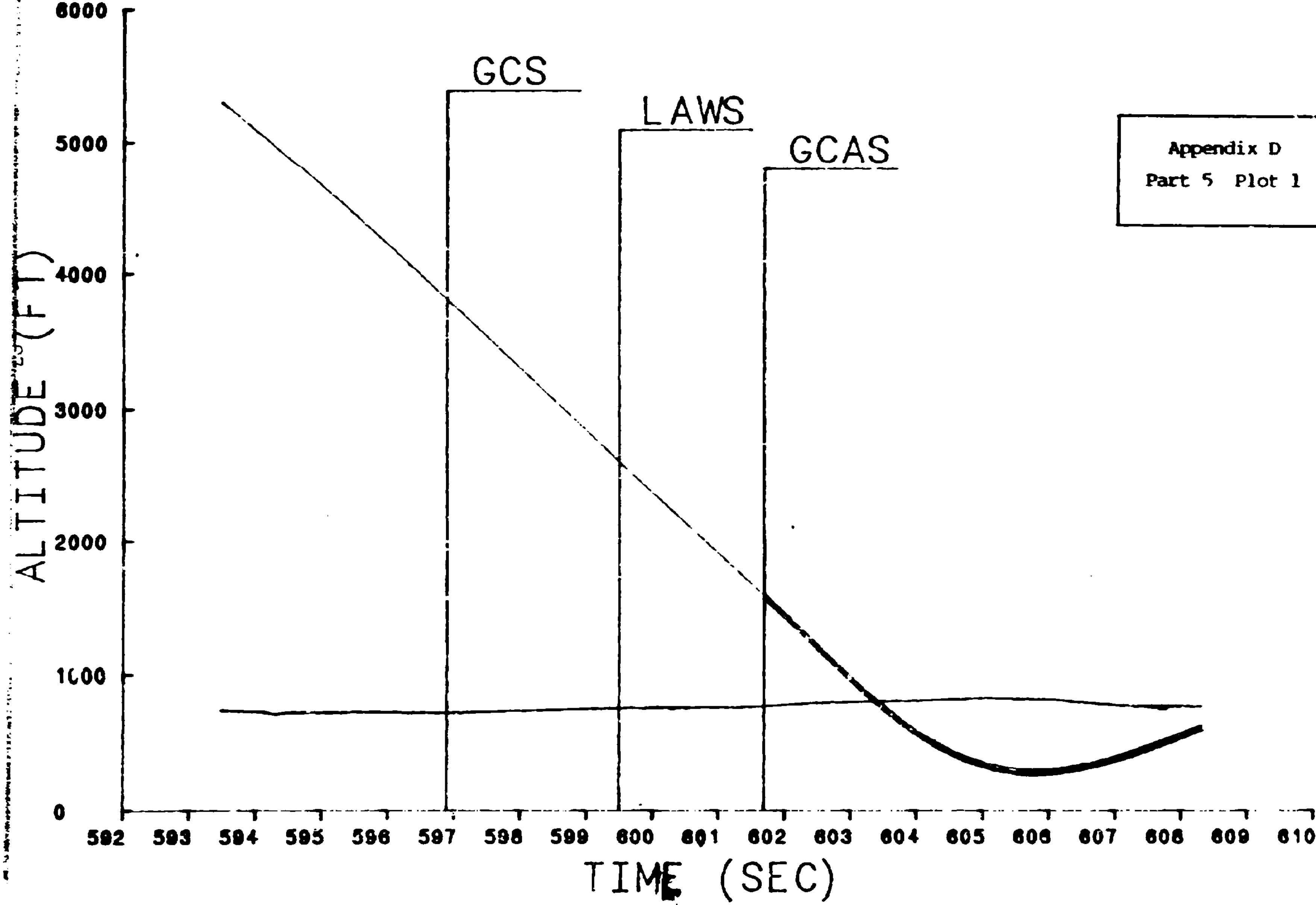


Appendix D
Part 4 Plot 7

GCAS MISSION 16 SUBJECT 1

EVENT #1

CAS	626	632	641	648	654	659	662	669	672	672	647	610	568	550	544
FPA	−45	−45	−45	−45	−45	−45	−45	−44	−44	−39	−26	−9	8	17	22
ROLL	1	1	−1	−1	−1	−1	−1	−1	−2	−2	−2	−3	−4	0	4
G	0.5	0.5	0.7	0.7	0.8	0.8	0.8	0.8	0.8	3.2	6.5	6.8	6.3	3.1	1.8

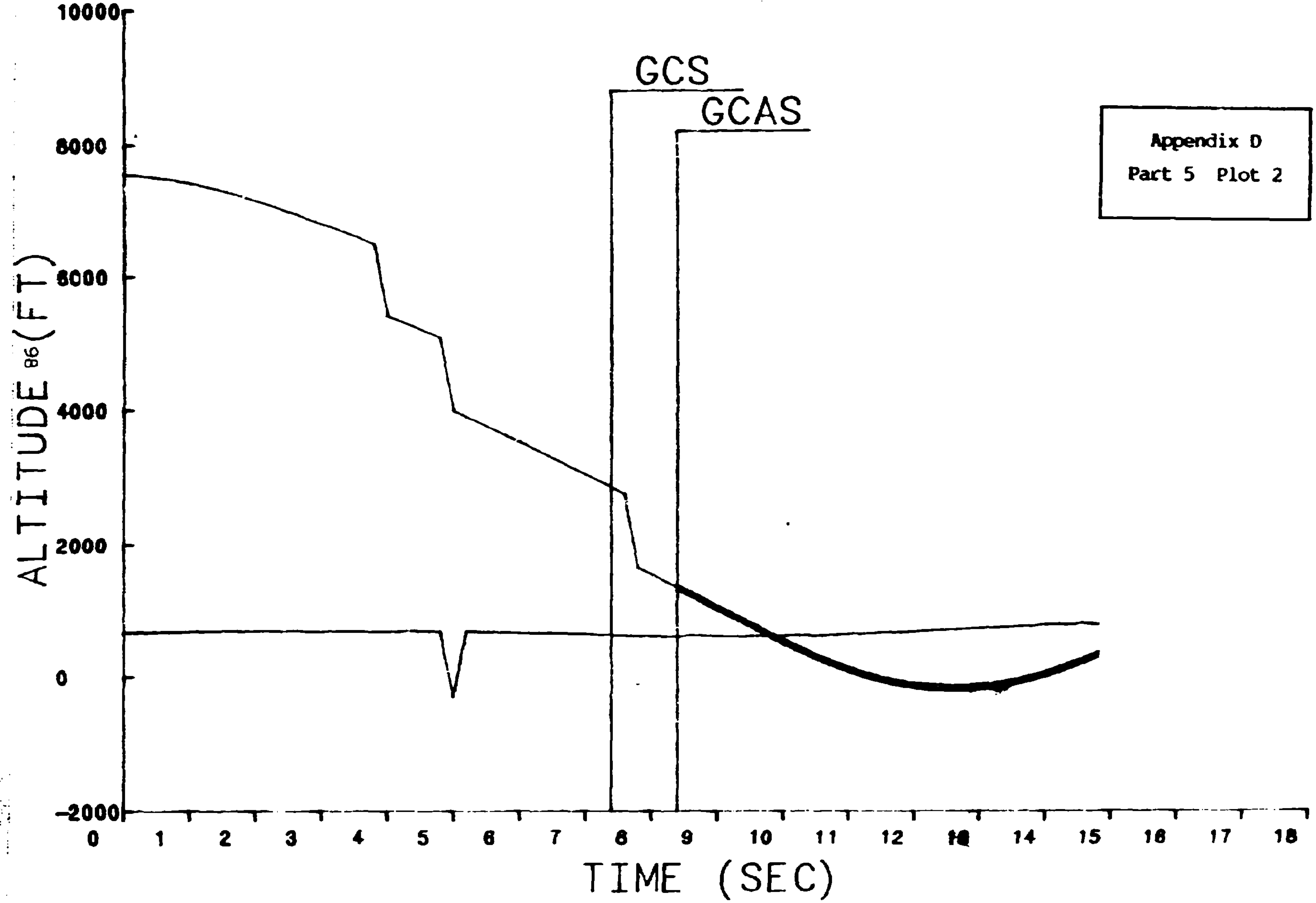


Appendix D
Part 5 Plot 1

GCAS MISSION 16 SUBJECT 2

EVENT #1

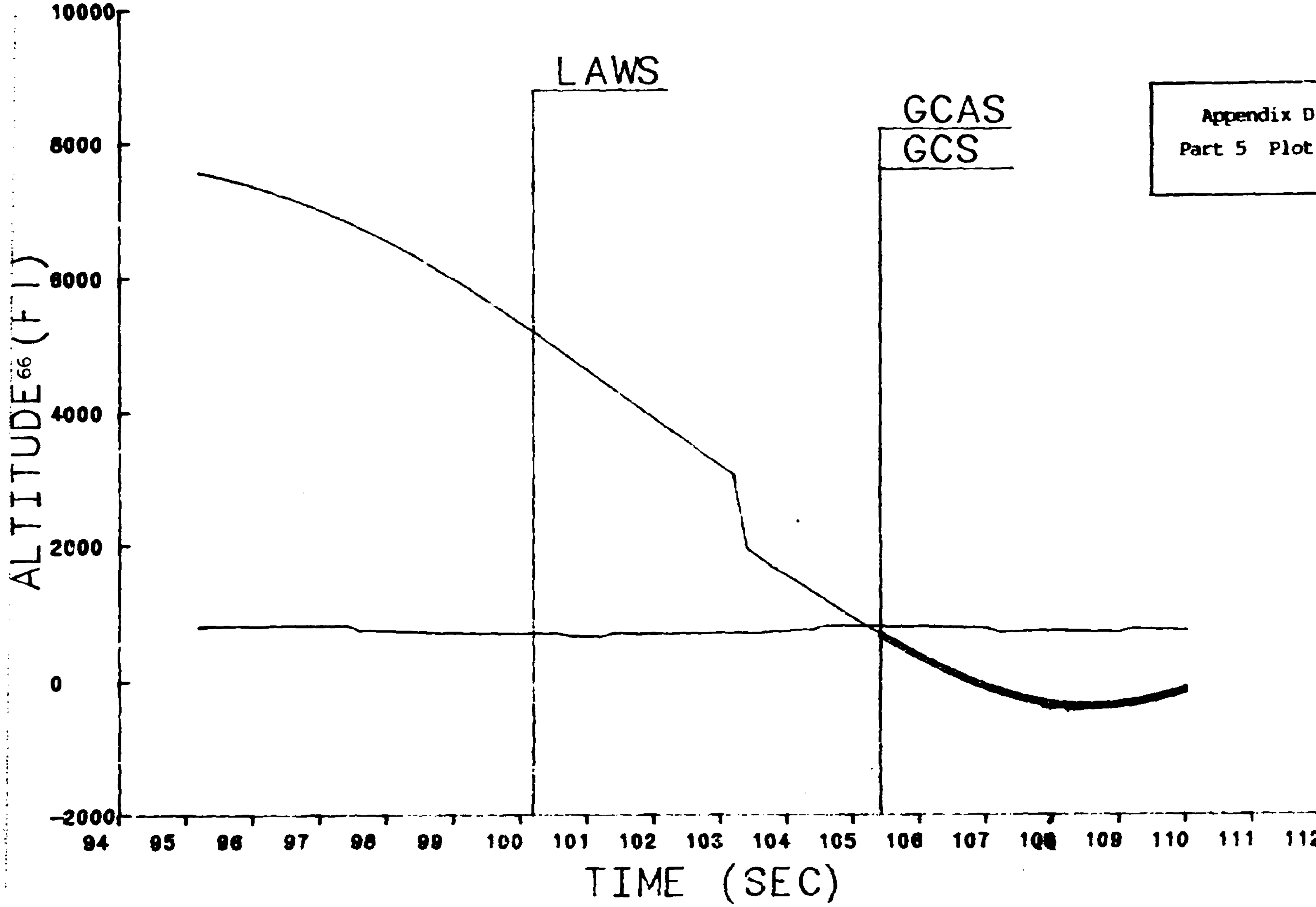
CAS	506	509	535	560	600	634	667	700	719	761	772	767	733	686	621
FPA	−21	−37	−45	−45	−46	−47	−47	−46	−44	−42	−30	−14	3	22	43
ROLL	176	171	85	55	35	5	−3	−5	−3	2	−6	−17	−30	−3	−14
G	4.0	2.9	2.1	2.0	−0.1	0.7	0.−	1.3	1.2	3.4	7.2	7.3	8.5	8.7	8.3



GCAS MISSION 16 SUBJECT 2

EVENT #2

CAS	644	655	668	684	693	716	733	747	767	783	794	790	779	723	658
FPA	-27	-38	-50	-63	-77	-90	-76	-68	-58	-50	-42	-28	-11	8	28
ROLL	172	-179	-179	176	-174	-2	-2	-2	-2	0	-4	-7	11	-20	-11
G	2.6	3.5	3.9	4.3	4.8	4.9	4.8	4.6	4.3	3.8	4.5	7.7	8.6	8.6	6.8

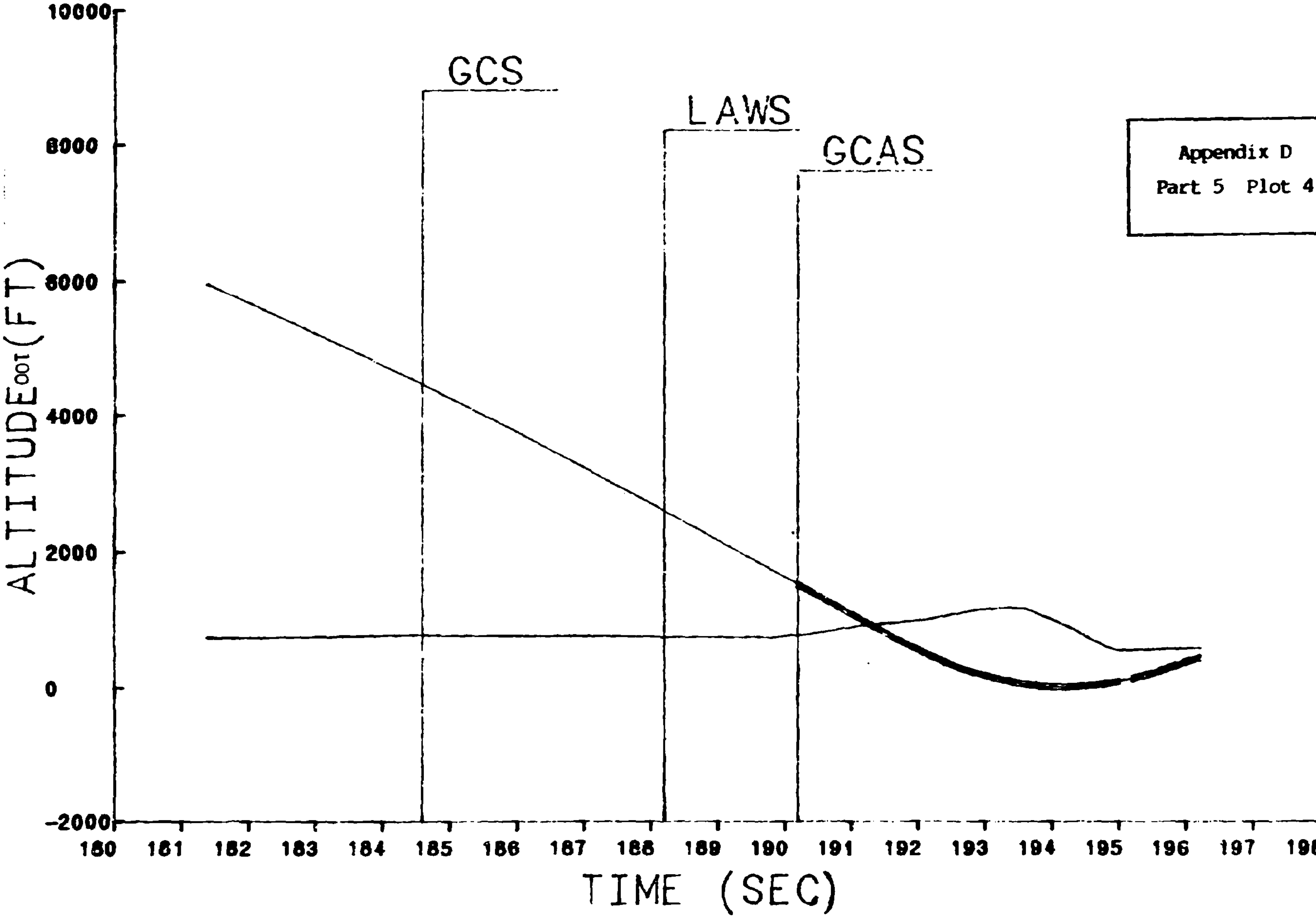


Appendix D
Part 5 Plot 3

GCAS MISSION 16 SUBJECT 2

EVENT #3

CAS	709	735	754	774	793	804	829	845	857	874	882	871	839	814	760
FPA	-40	-40	-41	-41	-41	-40	-40	-40	-39	-39	-31	-17	0	18	27
ROLL	-2	-2	-1	-1	-1	-1	-1	-1	-1	-2	-12	-14	2	-5	2
G	0.4	0.8	0.4	0.8	0.8	0.9	0.-	0.9	0.9	1.0	7.0	8.3	8.7	8.8	2.1

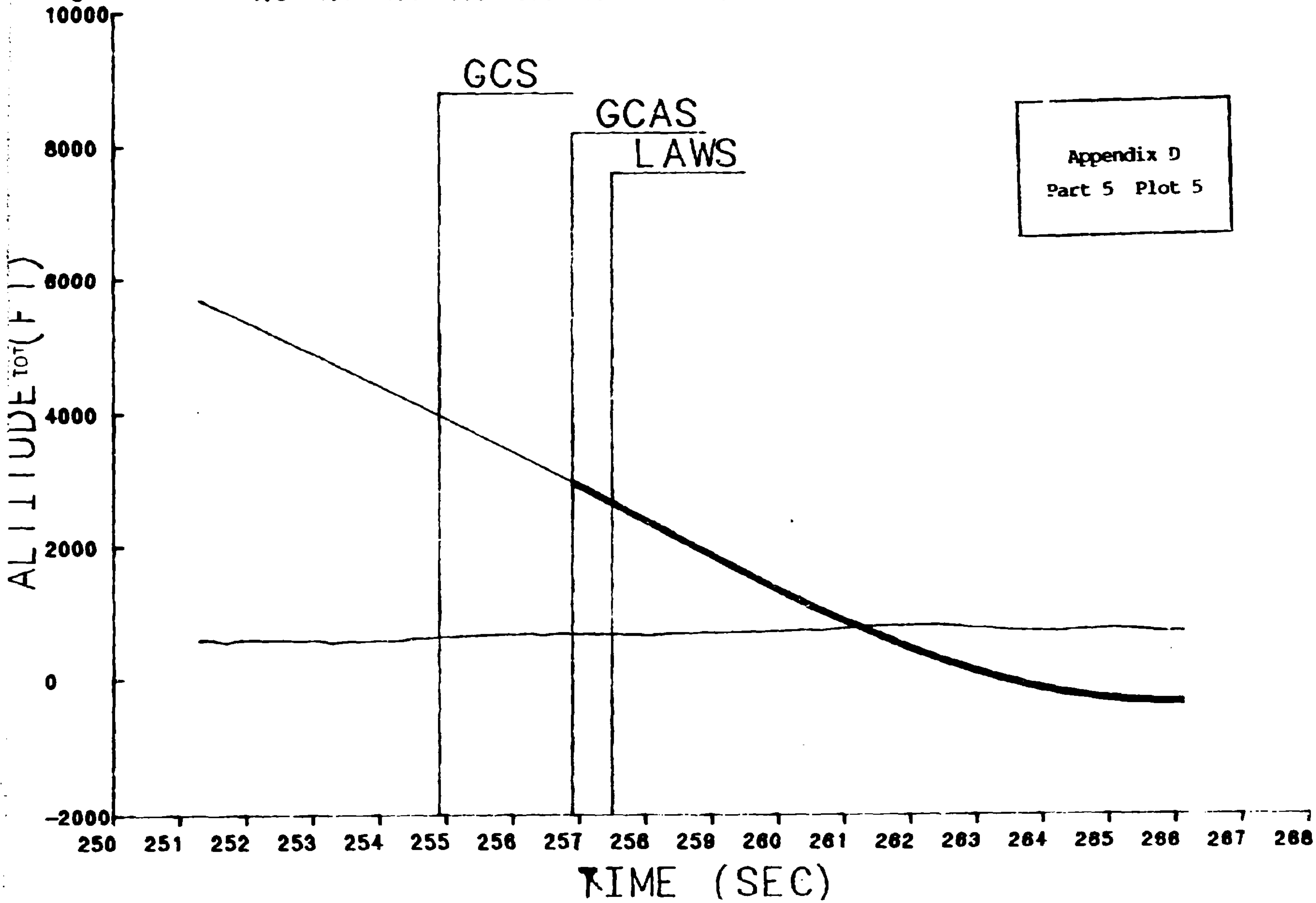


Appendix D
Part 5 Plot 4

GCAS MISSION '6 SUBJECT 4

EVENT #1

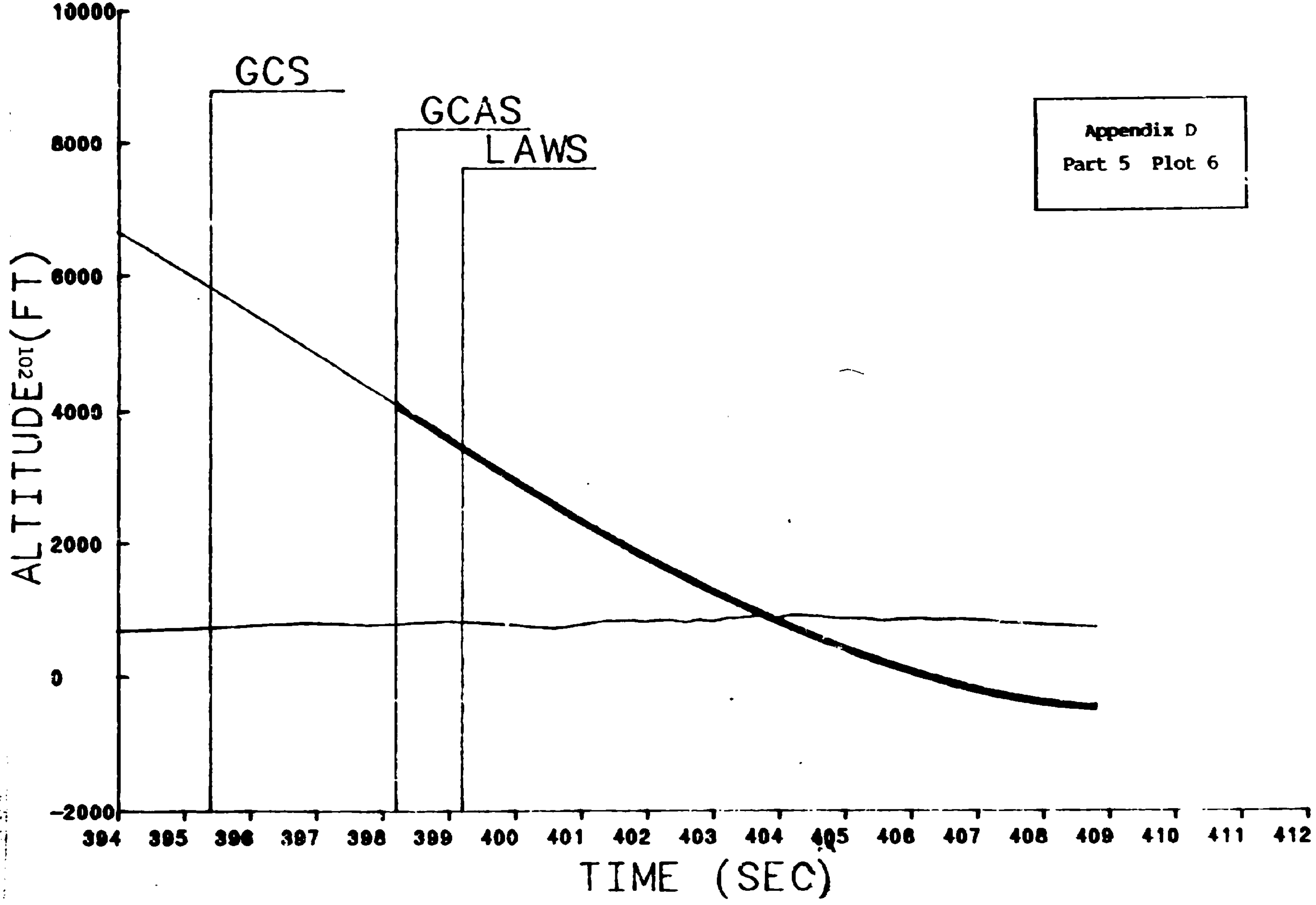
CAS	622	642	670	693	715	737	749	779	802	816	839	851	859	864	864
FPA	-50	-47	-45	-45	-45	-44	-45	-43	-39	-33	-27	-20	-13	-7	1
ROLL	-7	-6	-1	-16	—	-3	-3	-3	-3	-3	-4	-4	-4	-5	-5
G	1.5	1.7	1.3	0.9	0.8	0.6	0.7	2.4	3.1	3.5	3.8	4.0	4.1	4.3	4.6



GCAS MISSION 16 SUBJECT 7

EVENT #1

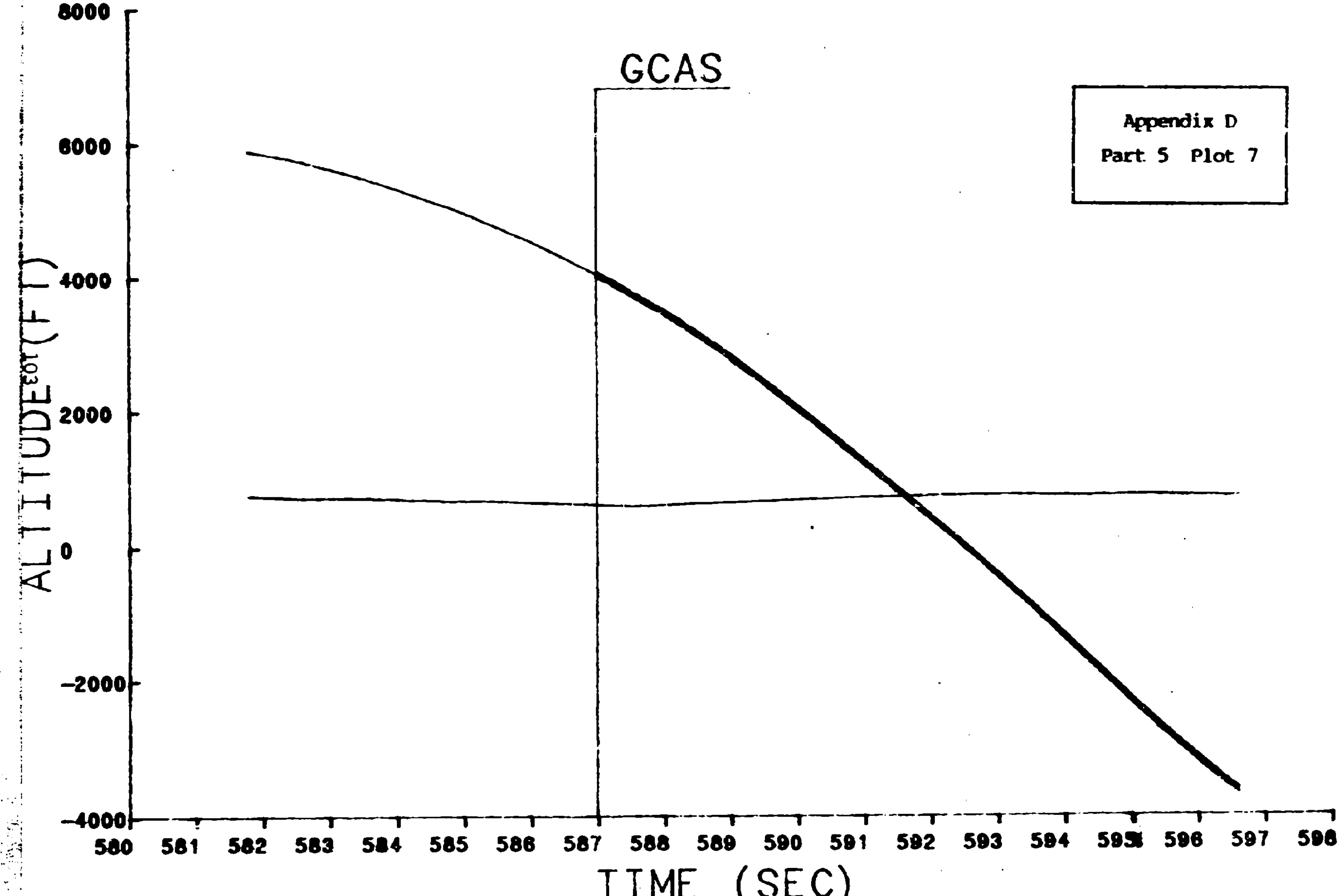
CAS	832	859	886	911	935	956	973	985	994	1000	1003	1003	1002	995	982
FPA	-48	-45	-44	-44	-43	-41	-38	-34	-30	-26	-22	-18	-15	-10	-3
ROLL	-2	-2	-2	-2	-2	-2	-2	-3	-2	-1	1	1	2	2	1
G	1.1	0.9	1.0	0.9	1.6	2.3	2.7	2.8	3.0	3.[illegible]	3.2	3.0	3.0	4.4	4.8



GCAS MISSION 16 SUBJECT 7

EVENT #2

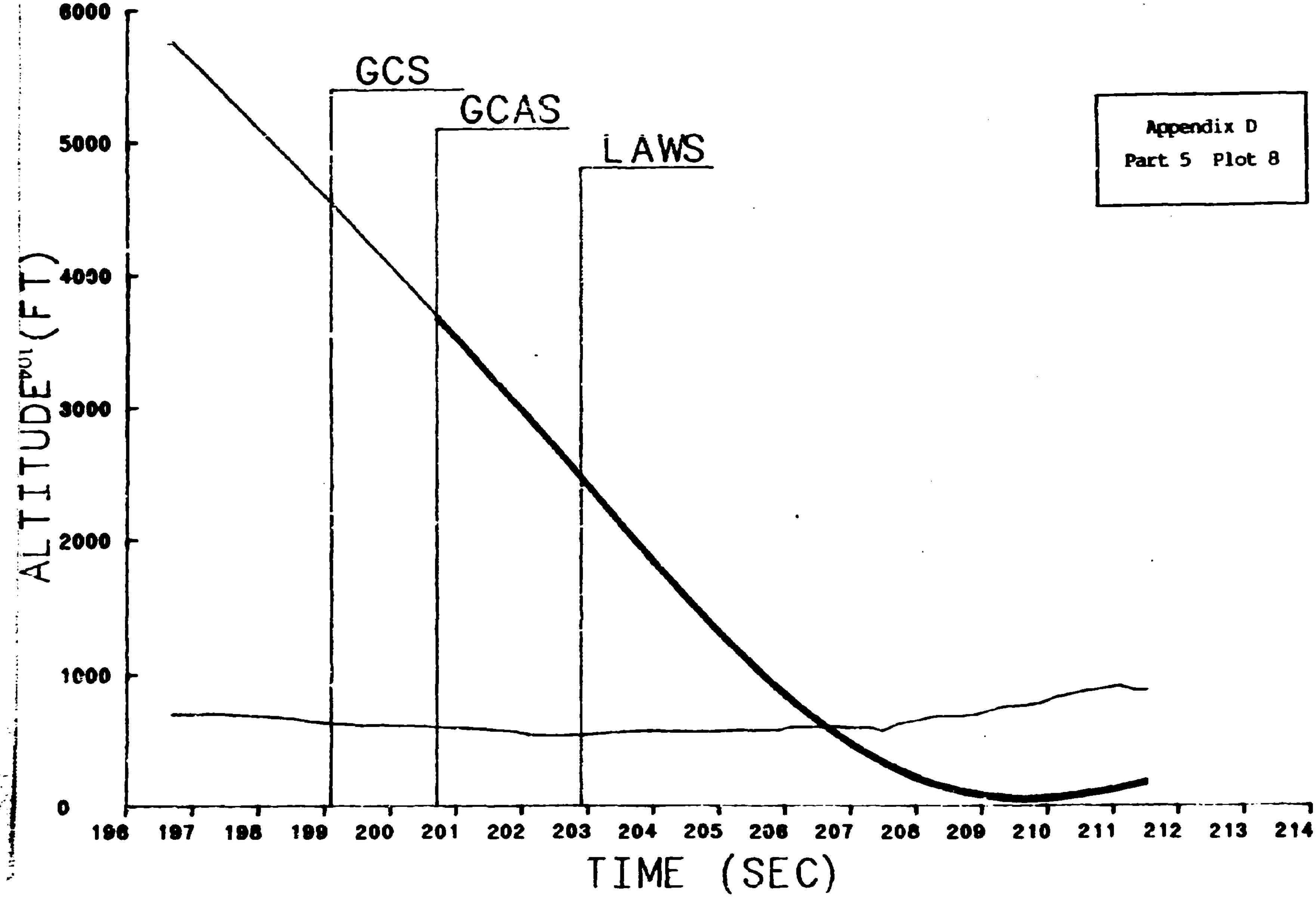
CAS	672	692	715	741	767	795	821	848	876	905	931	947	951	948	948
FPA	-20	-26	-32	-37	-41	-47	-56	-66	-66	-63	-66	-78	-85	-87	-51
ROLL	-178	-178	-178	-178	-178	-179	178	157	-42	-54	154	129	6	7	10
G	1.4	1.3	1.2	1.2	1.2	2.4	4.6	2.9	1.9	2.8	2.9	8.0	9.1	9.8	8.6



GCAS MISSION 16 SUBJECT 8

EVENT #1

CAS	696	719	742	763	783	803	822	836	838	833	823	805	775	740	714
FPA	−46	−45	−45	−45	−45	−45	−44	−40	−34	−27	−19	−11	−2	6	9
ROLL	1	1	1	2	2	1	1	0	−1	−1	−2	0	0	1	0
G	0.7	1.2	1.0	0.8	0.6	0.7	2.0	3.2	3.9	4.4	4.6	4.7	4.8	3.0	2.0

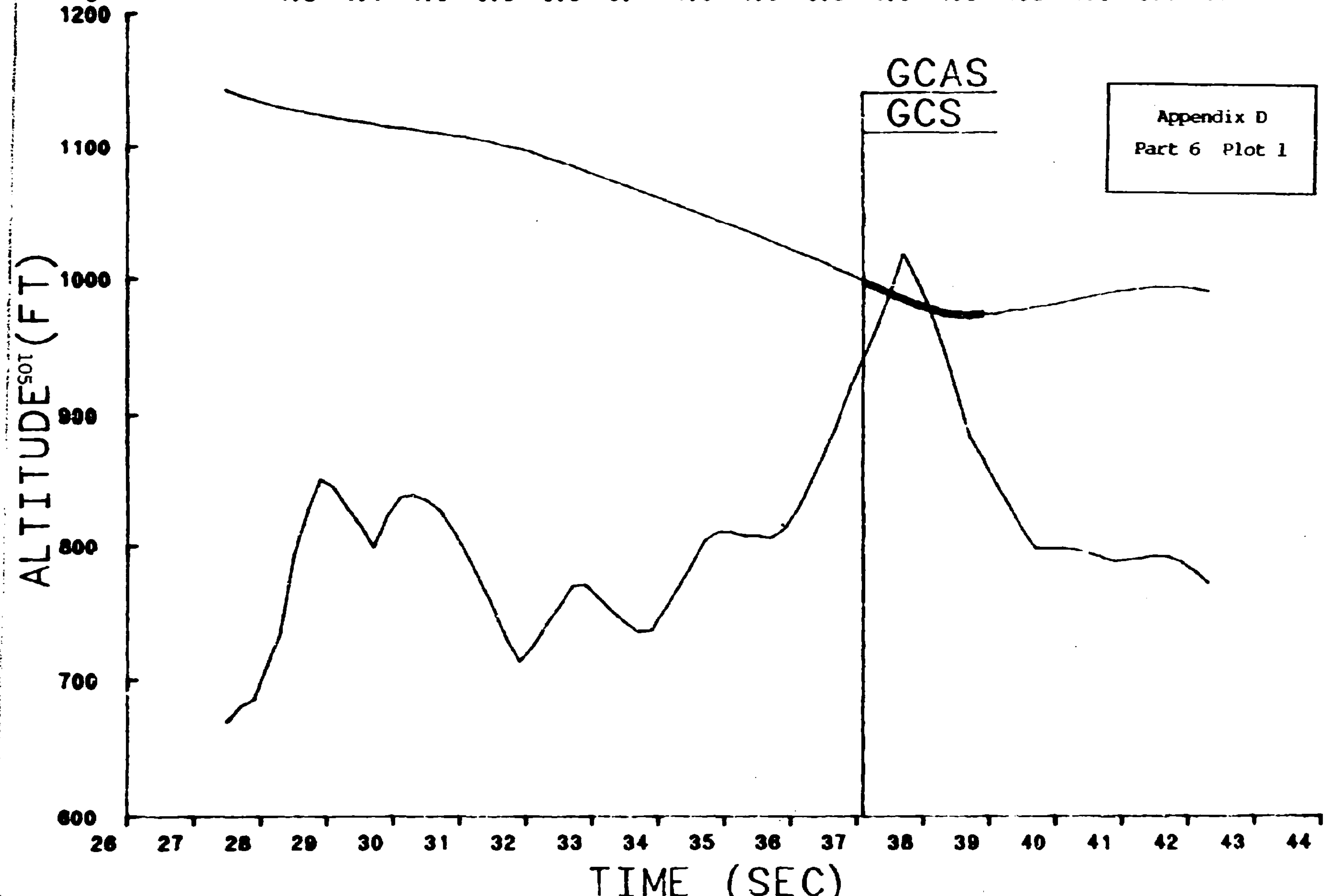


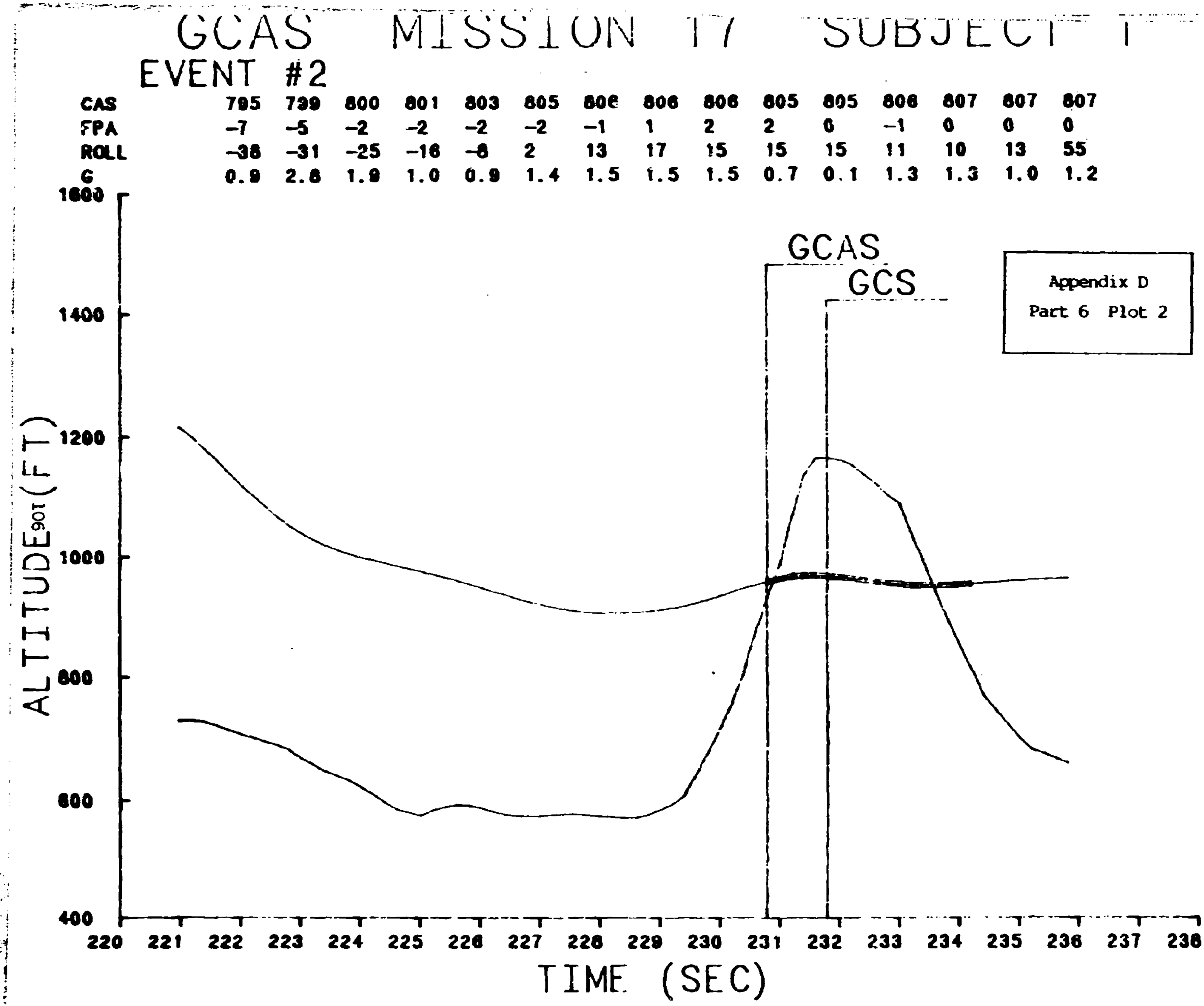
Appendix D
Part 5 Plot 8

GCAS MISSION 17 SUBJECT 1

EVENT #1

CAS	735	73_	735	735	736	736	737	737	738	738	739	738	737	738	738
FPA	−1	−1	−1	−1	−1	−2	−2	−2	−2	−2	−1	1	1	0	−1
ROLL	17	15	4	1	1	3	3	3	9	11	6	5	5	5	5
G	1.3	1.1	1.0	0.9	0.9	0.–	1.0	1.0	0.9	1.0	1.8	1.5	1.0	0.8	0.7



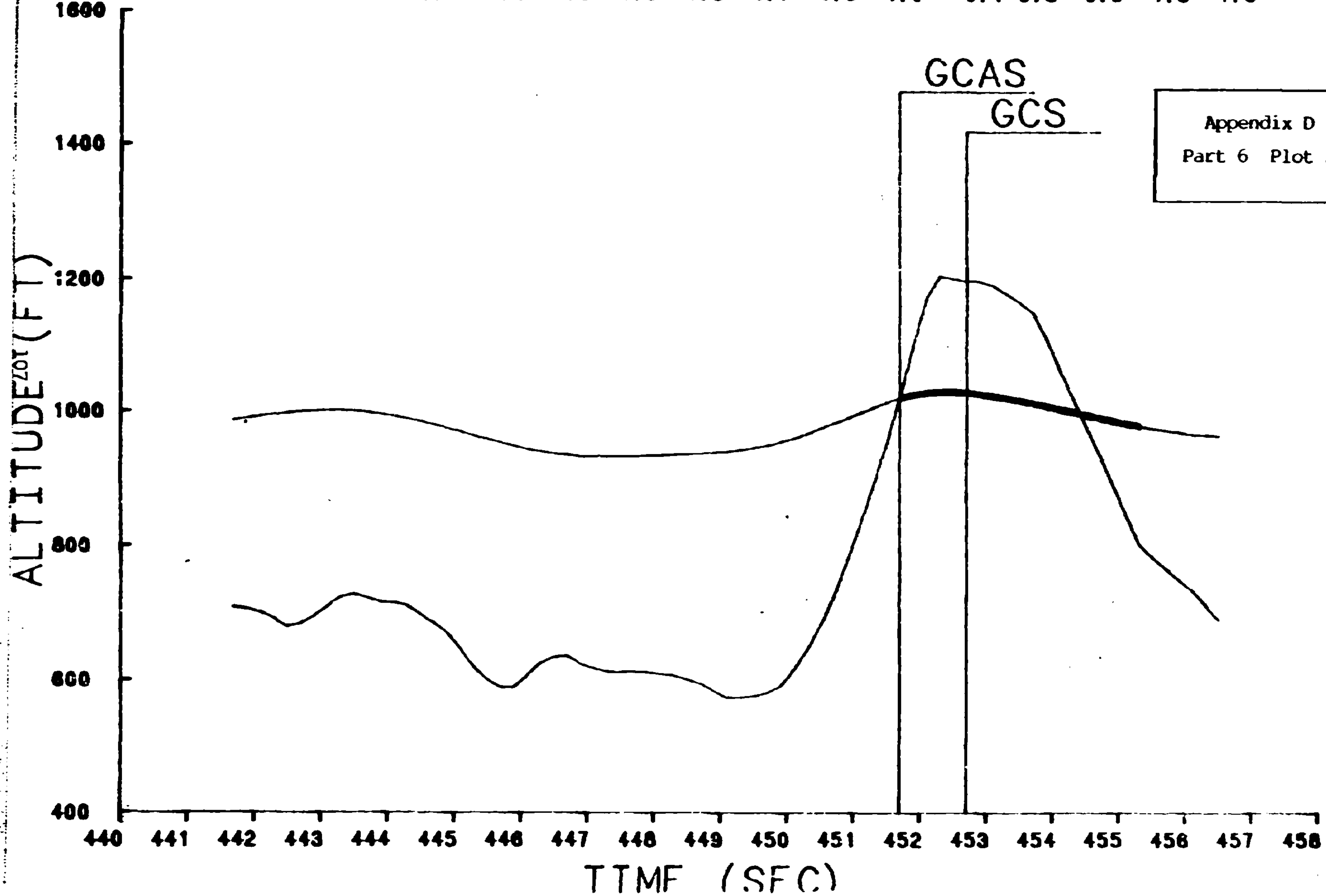


GCAS MISSION 17 SUBJECT I
EVENT #2
CAS 795 739 800 801 803 805 806 806 806 805 805 806 807 807 807
FPA -7 -5 -2 -2 -2 -2 -1 1 2 2 0 -1 0 0 0
ROLL -38 -31 -25 -16 -8 2 13 17 15 15 15 11 10 13 55
G 0.9 2.8 1.9 1.0 0.9 1.4 1.5 1.5 1.5 0.7 0.1 1.3 1.3 1.0 1.2
1600
1400
1200
1000
800
600
400
GCAS
GCS
Appendix D
Part 6 Plot 2
220 221 222 223 224 225 226 227 228 229 230 231 232 233 234 235 236 237 238
TIME (SEC)
ALTITUDE (FT)

GCAS MISSION 17 SUBJECT 1

EVENT #3

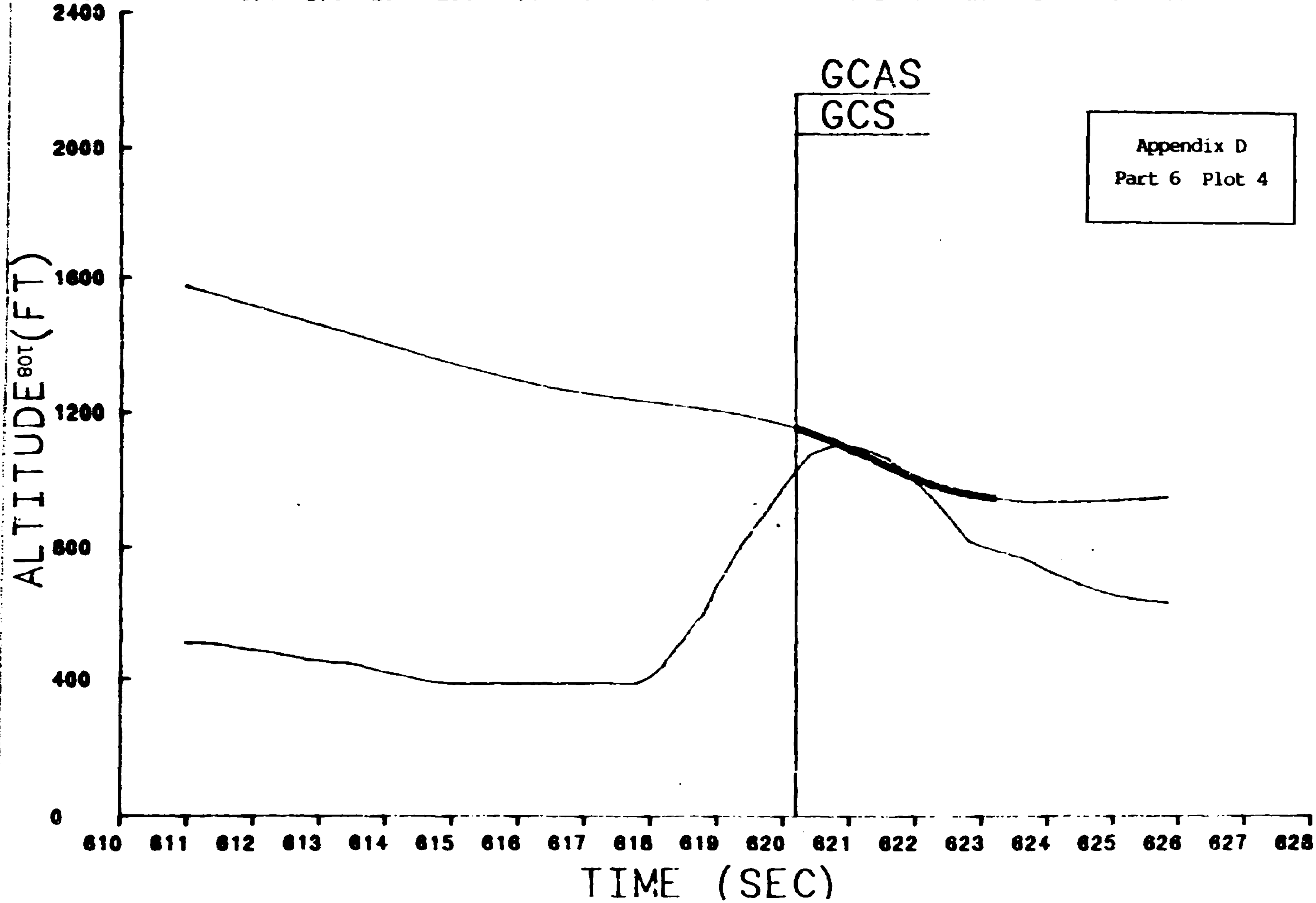
CAS	806	807	808	809	810	811	811	810	809	808	807	807	809	810	810
FPA	1	−1	−2	−2	−1	0	0	1	3	3	0	−1	−2	−1	0
ROLL	−2	0	0	5	13	19	23	18	17	18	19	19	19	22	20
G	0.8	0.3	0.6	1.2	1.5	1.3	1.3	1.7	1.5	1.0	−0.1	0.8	0.9	1.3	1.6



GCAS MISSION 17 SUBJECT 1

EVENT #4

CAS	834	836	838	841	843	845	846	849	850	852	856	858	859	859	859
FPA	−4	−4	−4	−4	−3	−2	−2	−2	−3	−5	−8	−3	−1	1	1
ROLL	69	68	67	52	42	31	24	22	22	22	7	1	−11	−12	−10
G	3.1	2.9	2.4	2.0	1.8	1.7	1.3	0.9	−0.0	−0.2	1.9	2.3	2.0	1.2	0.9

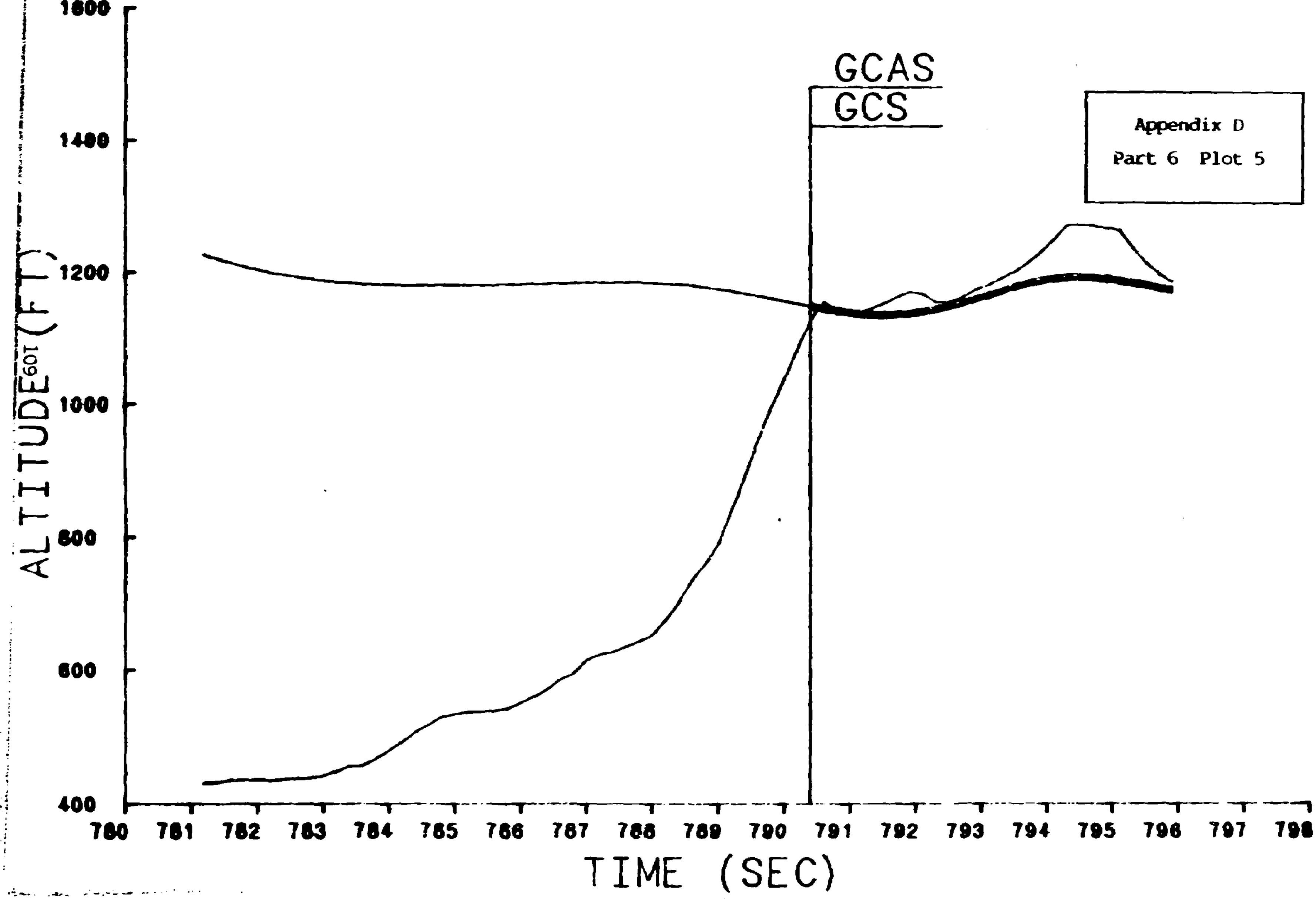


Appendix D
Part 6 Plot 4

GCAS MISSION 17 SUBJECT 1

EVENT #6

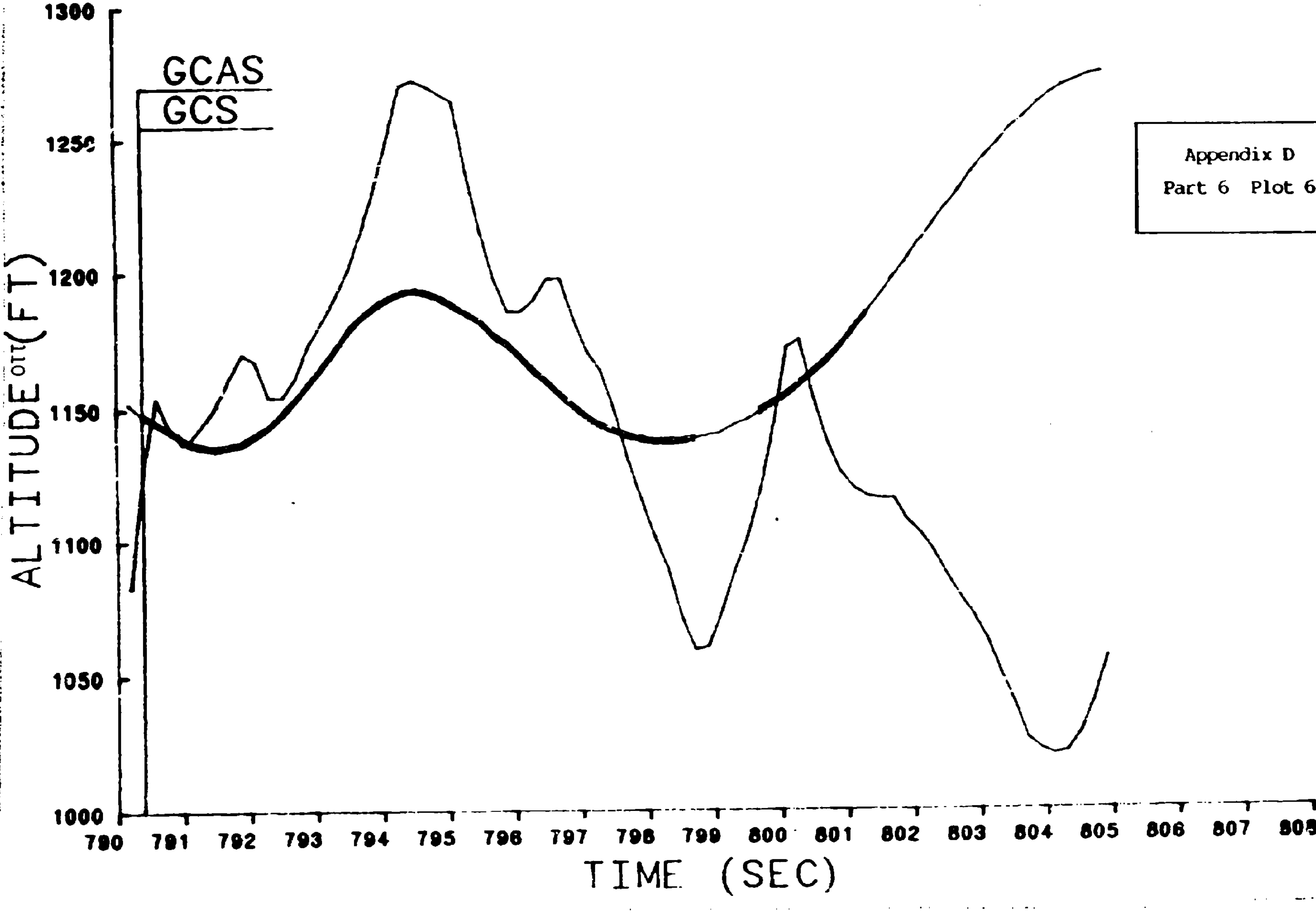
CAS	750	756	759	766	770	773	779	786	793	800	804	812	817	821	828
FPA	-2	-1	0	0	0	0	0	-1	-1	-1	1	2	1	-1	-2
ROLL	-83	-85	-87	-71	-72	-72	-72	-63	-39	-15	1	2	1	-14	-25
G	3.2	2.9	3.0	3.2	3.3	3.2	2.3	1.5	1.4	1.4	1.8	1.4	0.1	0.0	0.9



GCAS MISSION 17 SUBJECT 1

EVENT #7

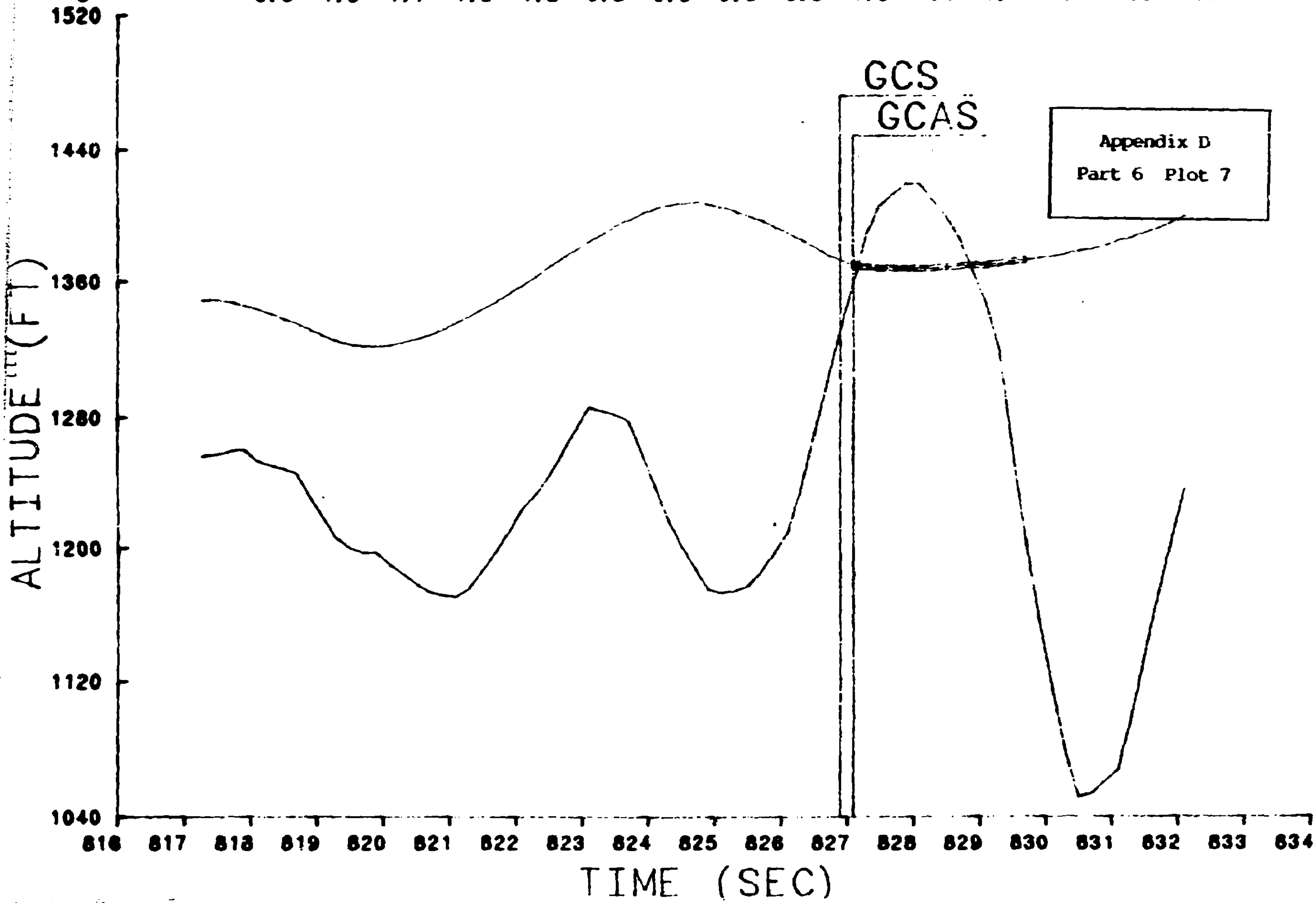
CAS	800	804	812	817	821	828	834	840	844	847	852	855	858	862	865
FPA	-1	1	2	1	-1	-2	-1	0	1	1	2	2	2	1	0
ROLL	-15	1	2	1	-14	-25	-26	-26	-30	-33	-32	-30	-30	-32	-32
G	1.4	1.8	1.4	0.1	0.0	0.9	1.4	1.7	1.7	1.3	1.7	1.2	1.1	0.7	0.7



Appendix D
Part 6 Plot 6

GCAS MISSION 17 SUBJECT 1
EVENT #8

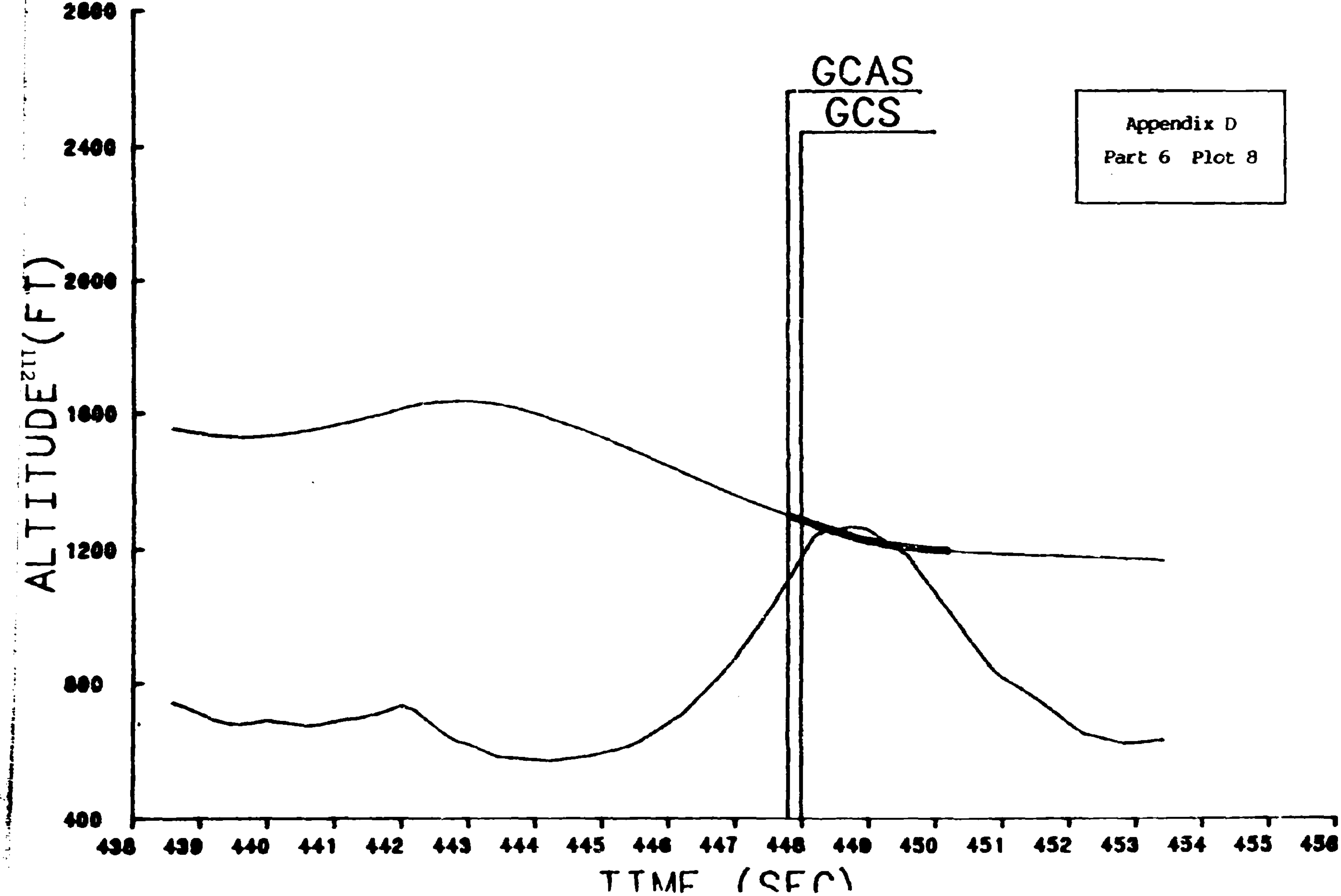
CAS	904	906	909	911	912	913	914	916	918	920	922	924	925	926	927
FPA	−1	−1	0	1	2	2	1	−1	−1	−1	0	0	0	1	1
ROLL	−12	−9	−9	−7	−4	−4	−2	−2	−4	−4	−3	−5	−20	−33	−44
G	0.6	1.3	1.7	1.3	1.2	0.8	0.5	0.3	0.8	1.8	1.1	1.1	1.1	1.5	1.5



GCAS MISSION 17 SUBJECT 2

EVENT #1

CAS	855	855	854	853	850	853	857	860	865	868	869	870	871	872	872
FPA	-1	2	3	2	-2	-5	-6	-6	-5	-4	-2	-1	-1	0	-1
ROLL	31	14	17	18	26	26	26	25	24	24	20	19	19	19	78
G	2.6	2.1	1.7	-0.5	-1.2	0.2	0.8	1.1	1.7	1.4	3.2	1.4	1.2	1.0	1.6

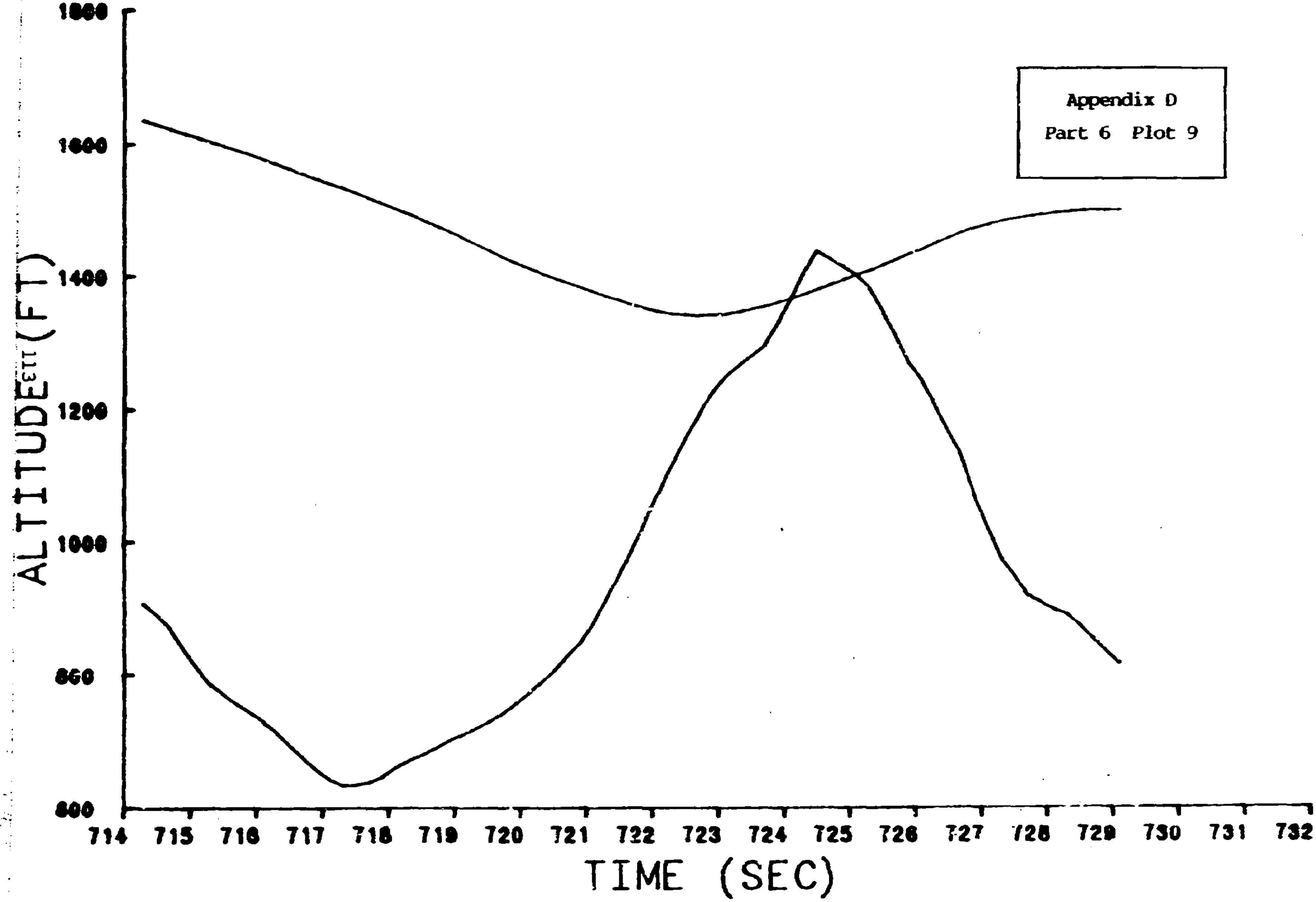


Appendix D
Part 6 Plot 8

GCAS MISSION 17 SUBJECT 2

EVENT #2

CAS	864	862	859	856	853	846	842	833	827	827	828	826	830	832	833
FPA	-2	-2	-3	-3	-3	-3	-2	-2	1	2	3	3	2	1	0
ROLL	-76	-77	-76	-78	-81	-73	-77	-80	-58	-54	-55	-54	-53	-52	-52
G	3.6	3.6	4.1	4.3	4.4	5.2	5.0	5.3	3.3	2.8	1.7	1.6	-0.1	0.8	1.1

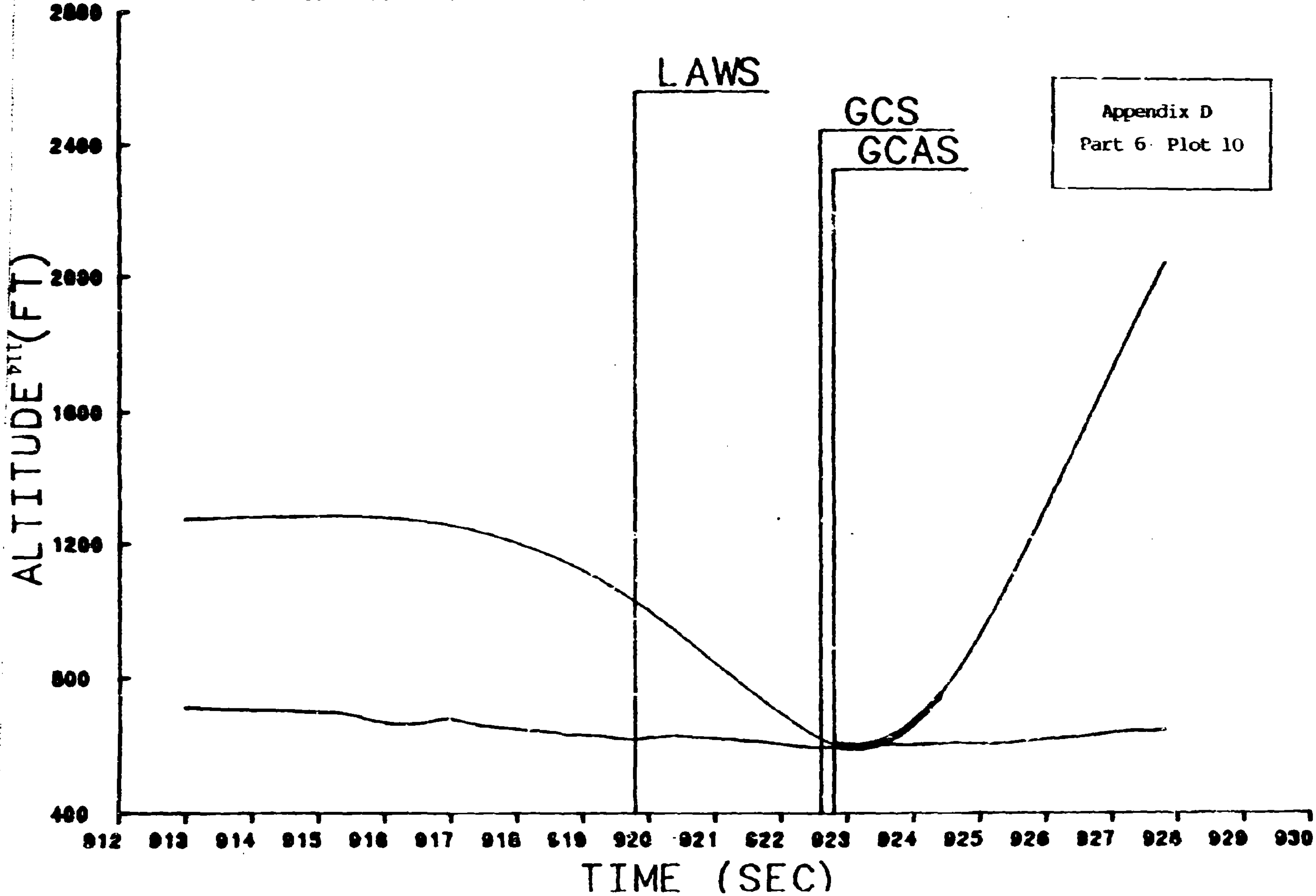


Appendix D
Part 6 Plot 9

GCAS MISSION 17 SUBJECT 2

EVENT #3

CAS	879	877	875	874	872	871	868	866	851	836	318	773	748	735	722
FPA	0	0	-1	-2	-4	-6	-9	-11	-10	-5	8	23	33	34	31
ROLL	-72	-74	-83	-88	-88	-91	-91	-83	-74	-31	-20	-18	-15	-16	-15
G	2.4	3.5	3.4	3.3	3.8	3.9	5.1	7.1	6.1	9.3	6.8	7.2	3.0	0.7	-0.8

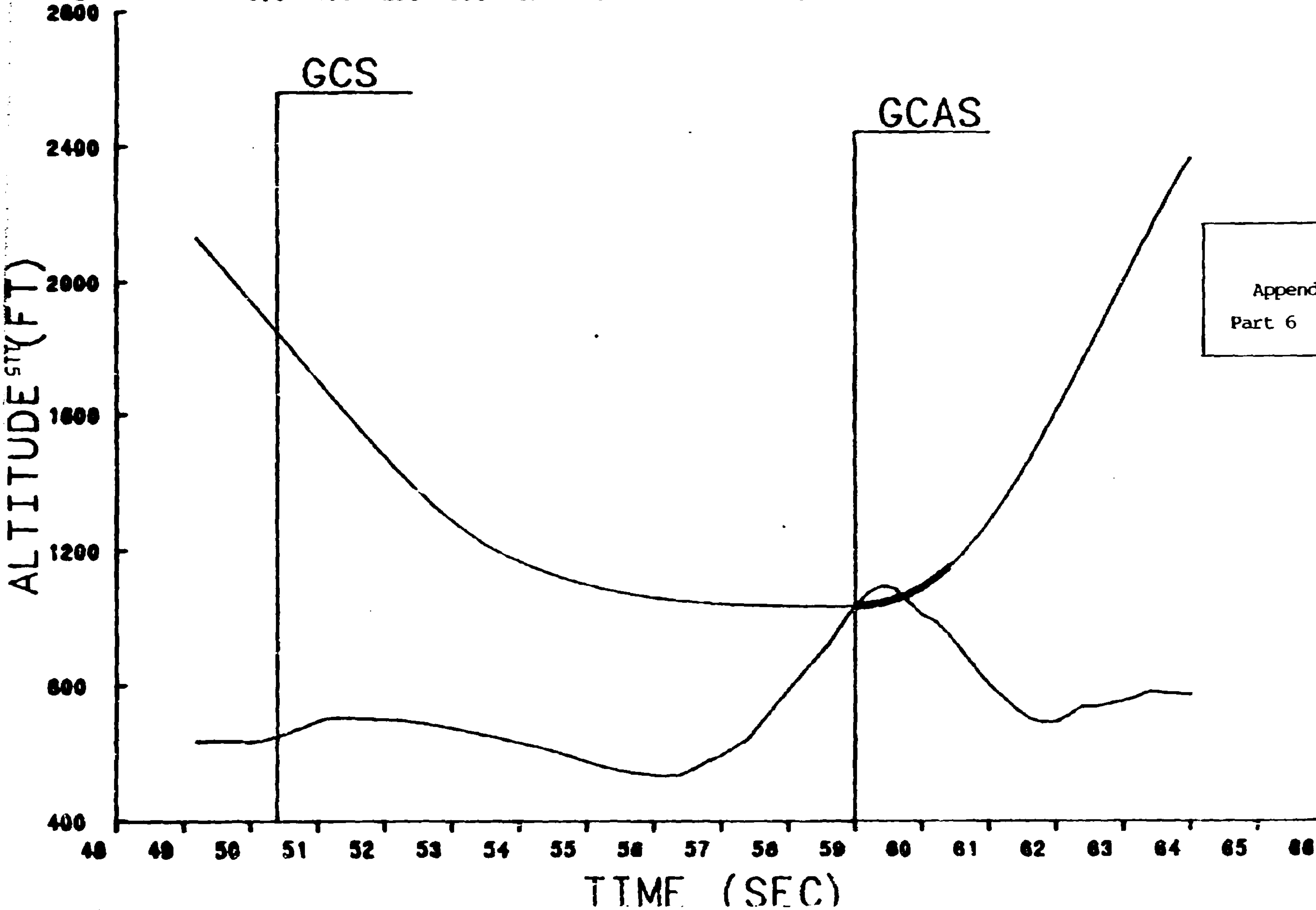


Appendix D
Part 6 Plot 10

GCAS MISSION 17 SUBJECT 4

EVENT #1

CAS	684	675	661	667	665	665	664	664	662	660	673	631	590	564	549
FPA	-21	-21	-18	-14	-7	-4	-3	-1	0	1	-	25	38	45	38
ROLL	7	6	6	5	5	4	4	3	14	13	13	-	4	96	-156
G	0.8	1.9	2.0	3.0	2.7	2.1	1.7	1.4	1.2	2.4	4.4	6.3	5.1	3.1	1.6

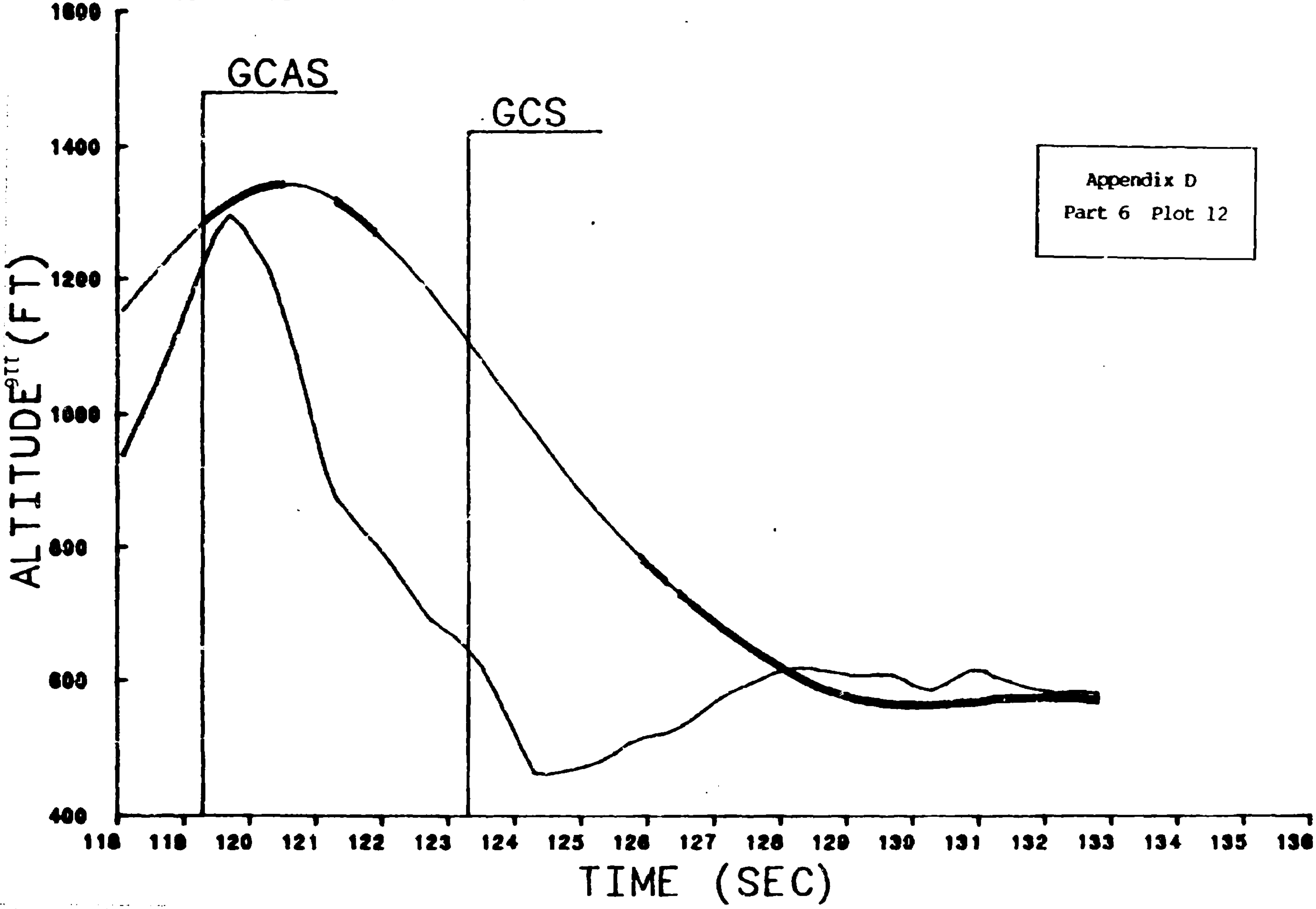


Appendix D
Part 6 Plot 11

GCAS MISSION 17 SUBJECI 4

EVENT #2

CAS	856	853	850	849	657	864	872	878	882	885	886	885	885	888	889
FPA	6	4	-2	-6	-8	-9	-8	-7	-5	-4	-2	0	1	0	0
ROLL	-10	-7	22	28	37	42	52	51	59	62	58	60	66	66	66
G	0.9	-1.2	-1.7	-0.2	0.4	0.9	2.5	2.8	2.8	3.0	3.4	3.4	2.9	1.9	1.8

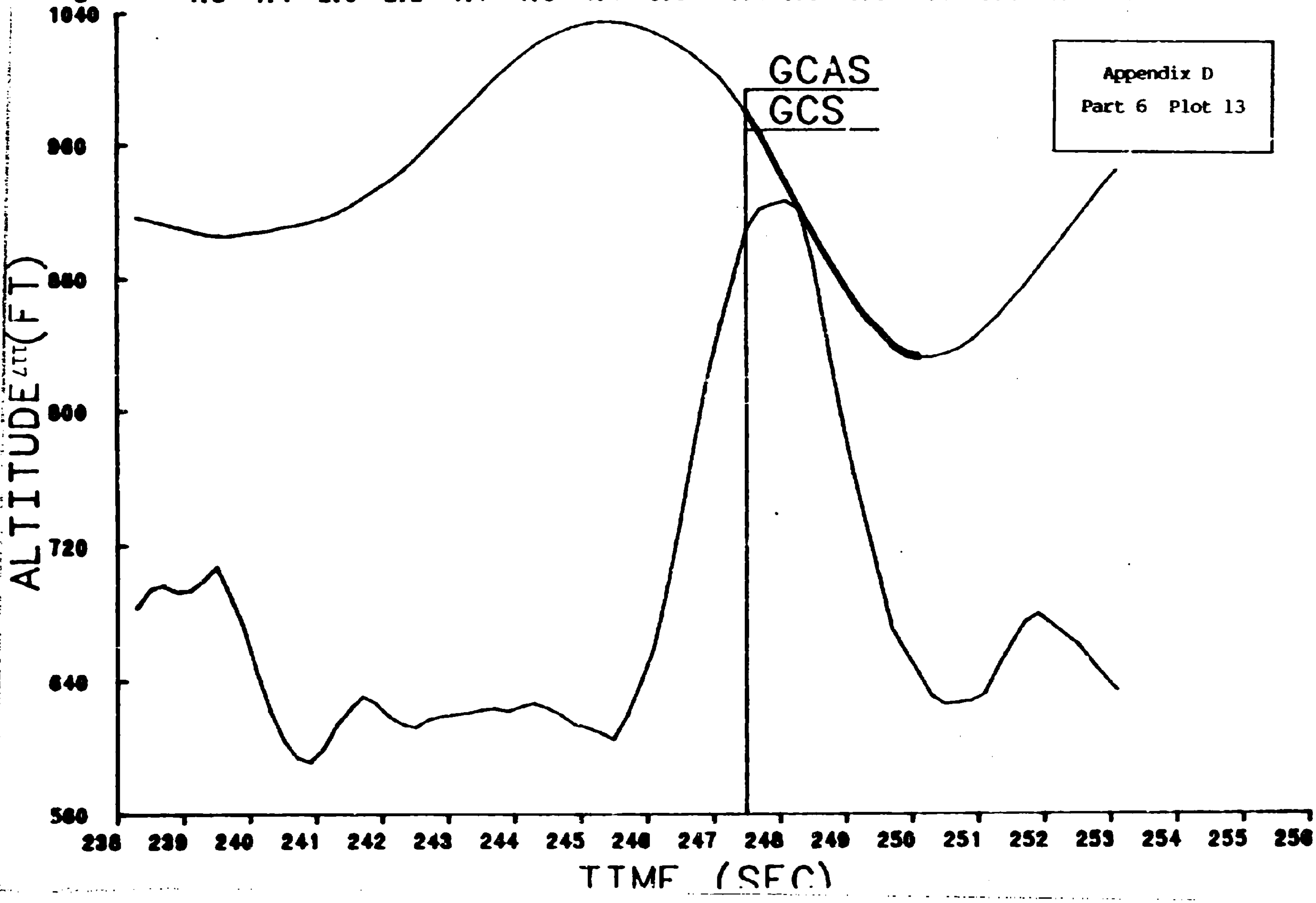


Appendix D
Part 6 Plot 12

GCAS MISSION 17 SUBJECT 4

EVENT #3

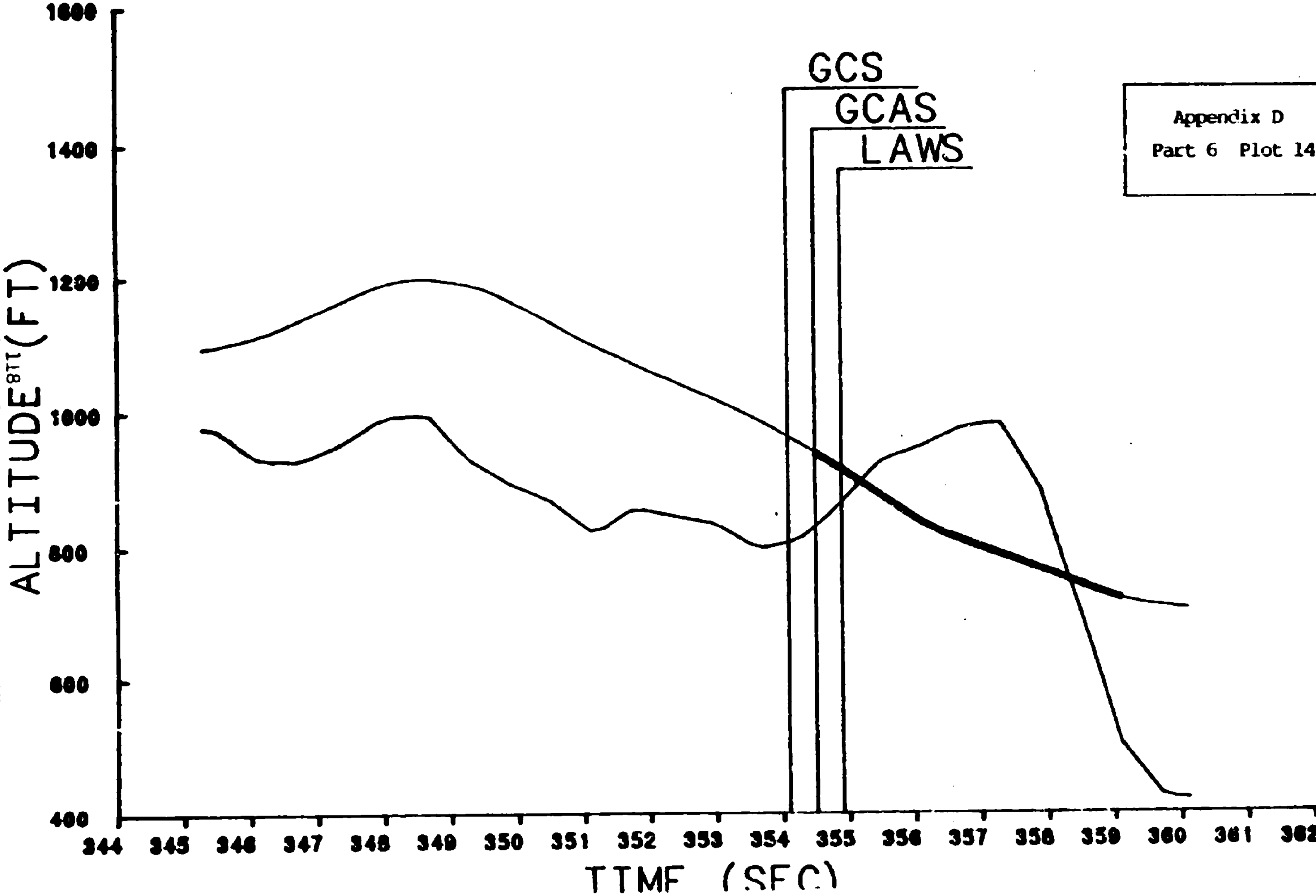
CAS	827	825	822	820	816	813	811	810	810	610	810	805	798	794	792
FPA	−1	1	1	2	3	2	1	−1	−3	−5	−4	−1	3	4	3
ROLL	19	35	41	51	56	68	65	71	27	5	62	49	47	50	57
G	1.3	1.4	2.0	2.2	1.7	1.3	1.1	0.9	−0.1	0.9	3.8	4.9	3.2	1.9	1.4



GCAS MISSION 17 SUBJECT 4

EVENT #4

CAS	899	900	901	901	904	909	912	916	918	922	926	928	930	932	933
FPA	2	3	2	−1	−3	−3	−3	−3	−3	−4	−4	−2	−2	−2	−1
ROLL	−24	−11	−3	1	4	3	3	3	1	−44	−39	−36	−38	−35	−28
G	1.9	1.2	−0.3	−0.4	0.9	1.7	1.0	0.8	0.9	0.9	2.7	2.1	1.1	2.2	1.2

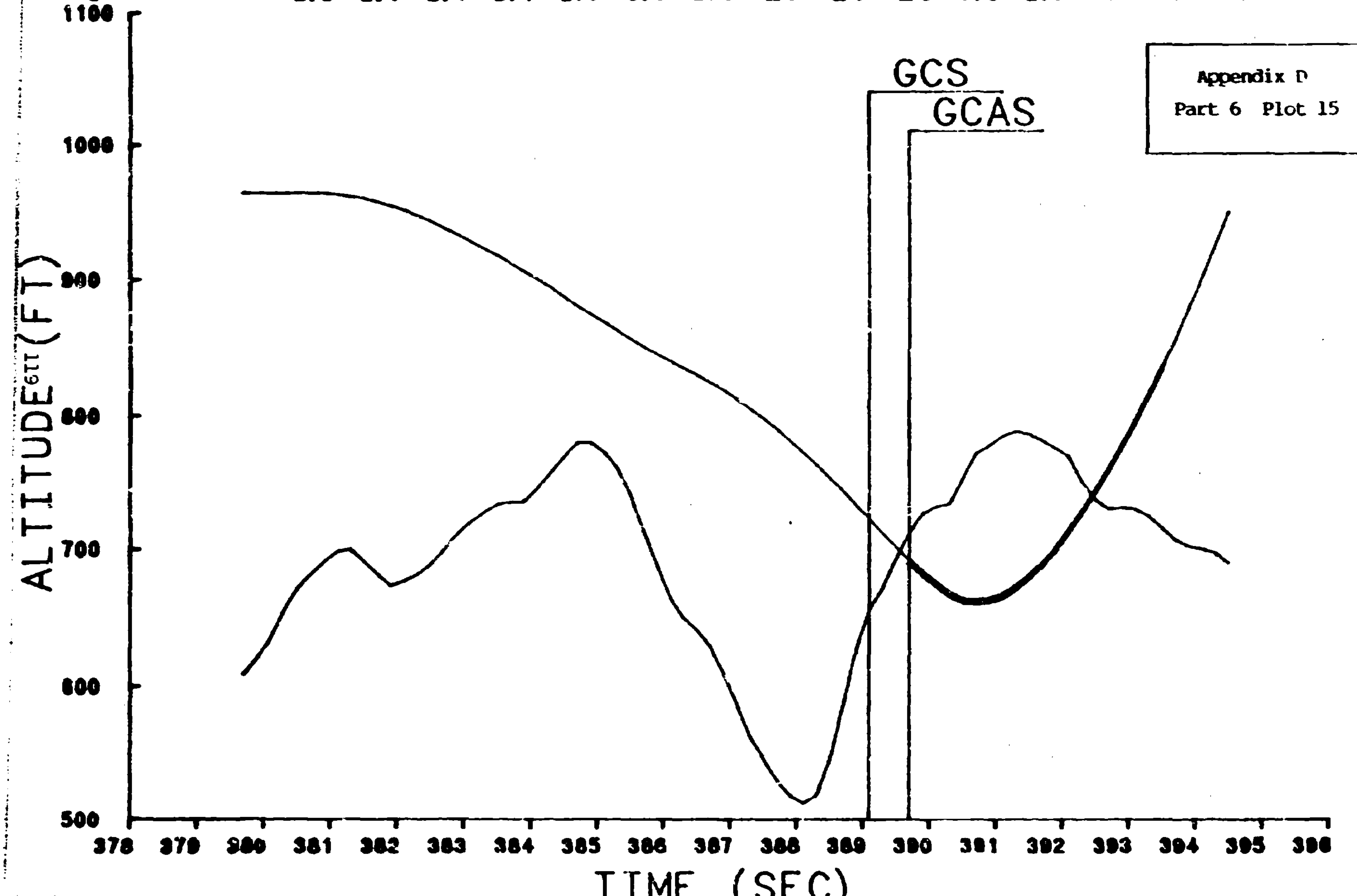


Appendix D
Part 6 Plot 14

GCAS MISSION 17 SUBJECT 4

EVENT #5

CAS	913	915	917	918	919	921	922	924	927	929	930	928	927	924	922
FPA	0	−1	−1	−2	−2	−2	−2	−2	−3	−3	−1	3	5	6	8
ROLL	70	73	71	70	69	68	67	66	63	50	39	34	25	17	11
G	2.3	2.1	2.4	2.4	2.5	3.3	2.4	1.5	1.3	1.8	3.6	2.9	1.8	1.7	1.5

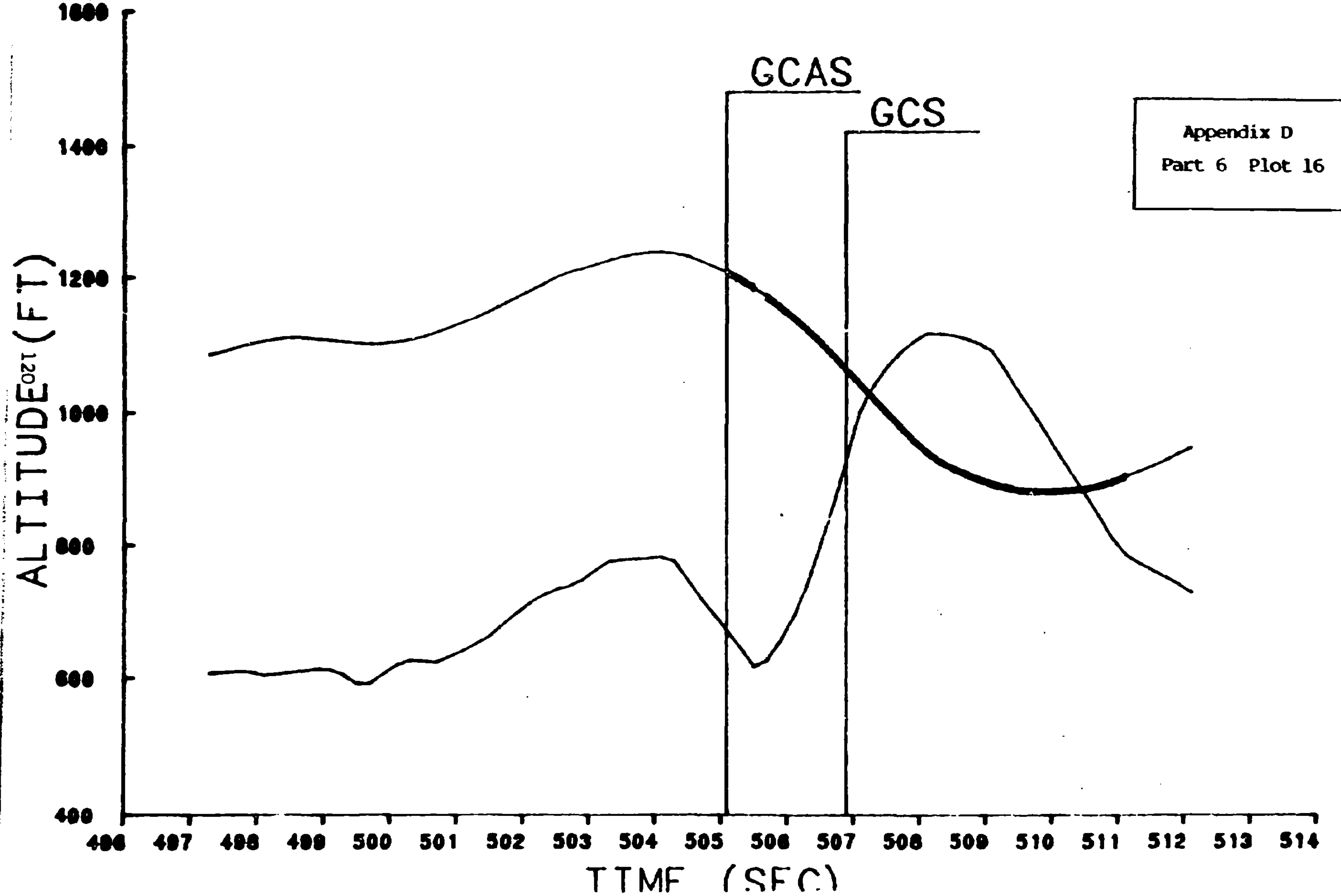


Appendix D
Part 6 Plot 15

GCAS MISSION 17 SUBJECT 4

EVENT #6

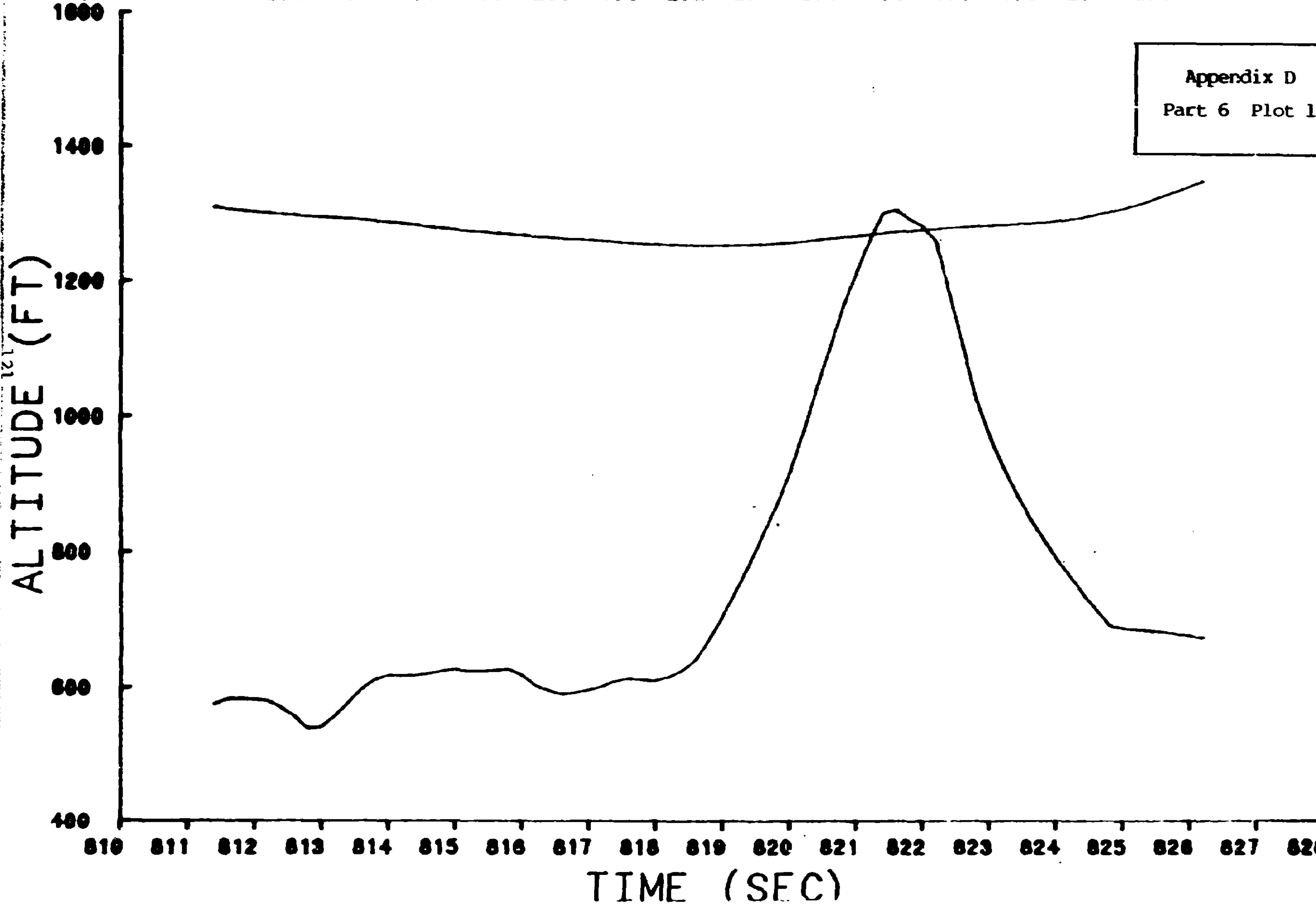
CAS	741	738	735	732	727	720	711	702	703	706	705	707	705	701	698
FPA	2	−1	1	3	4	2	0	−4	−7	−9	−7	−3	0	3	4
ROLL	−16	−29	−30	−26	15	83	100	94	86	−3	−9	−7	−7	−6	−5
G	0.1	0.6	2.4	1.7	1.1	5.4	3.7	2.4	0.2	0.8	3.1	2.0	1.7	1.6	1.5



GCAS MISSION 17 SUBJECT 4

EVENT #7

CAS	941	941	942	942	943	943	943	943	943	943	943	943	942	941	939
FPA	-1	0	-1	-1	0	0	0	0	1	1	0	0	1	2	2
ROLL	57	58	57	57	57	57	58	59	59	60	60	60	60	59	60
G	2.4	1.7	1.9	1.9	2.0	1.8	2.2	2.4	2.3	1.6	1.9	1.8	2.8	2.6	2.1



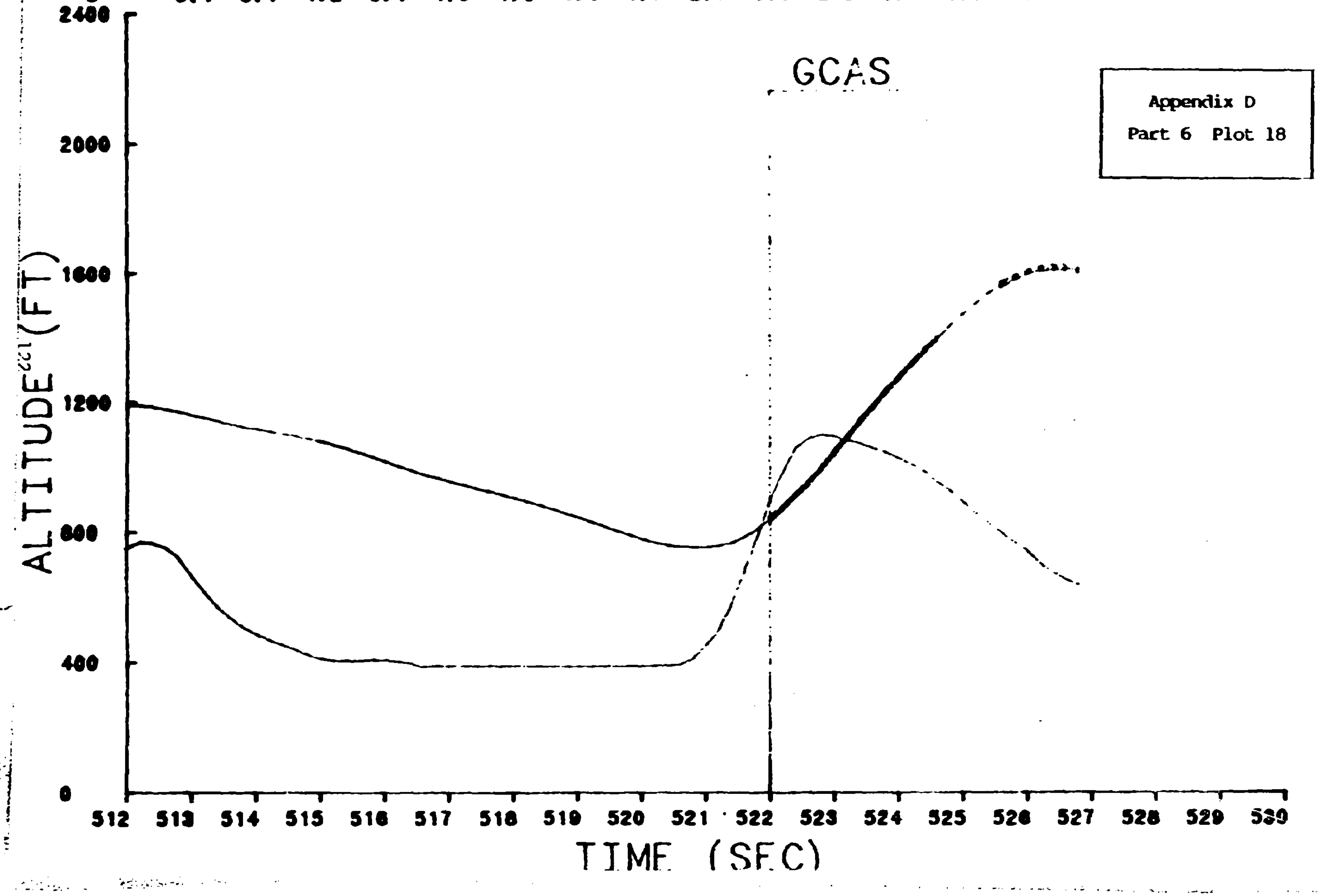
Appendix D

Part 6 Plot 17

GCAS MISSION 17 SUBJECT 5

EVENT #1

CAS	857	857	857	853	850	849	849	849	848	840	831	827	824	821	817
FPA	-3	-3	-3	-5	-4	-3	-4	-4	0	9	16	16	13	7	-3
ROLL	85	69	85	89	70	84	79	75	40	8	11	99	97	135	133
G	5.1	5.1	4.2	6.4	4.9	4.8	4.4	4.7	2.9	5.8	2.8	0.-	0.9	4.4	4.3

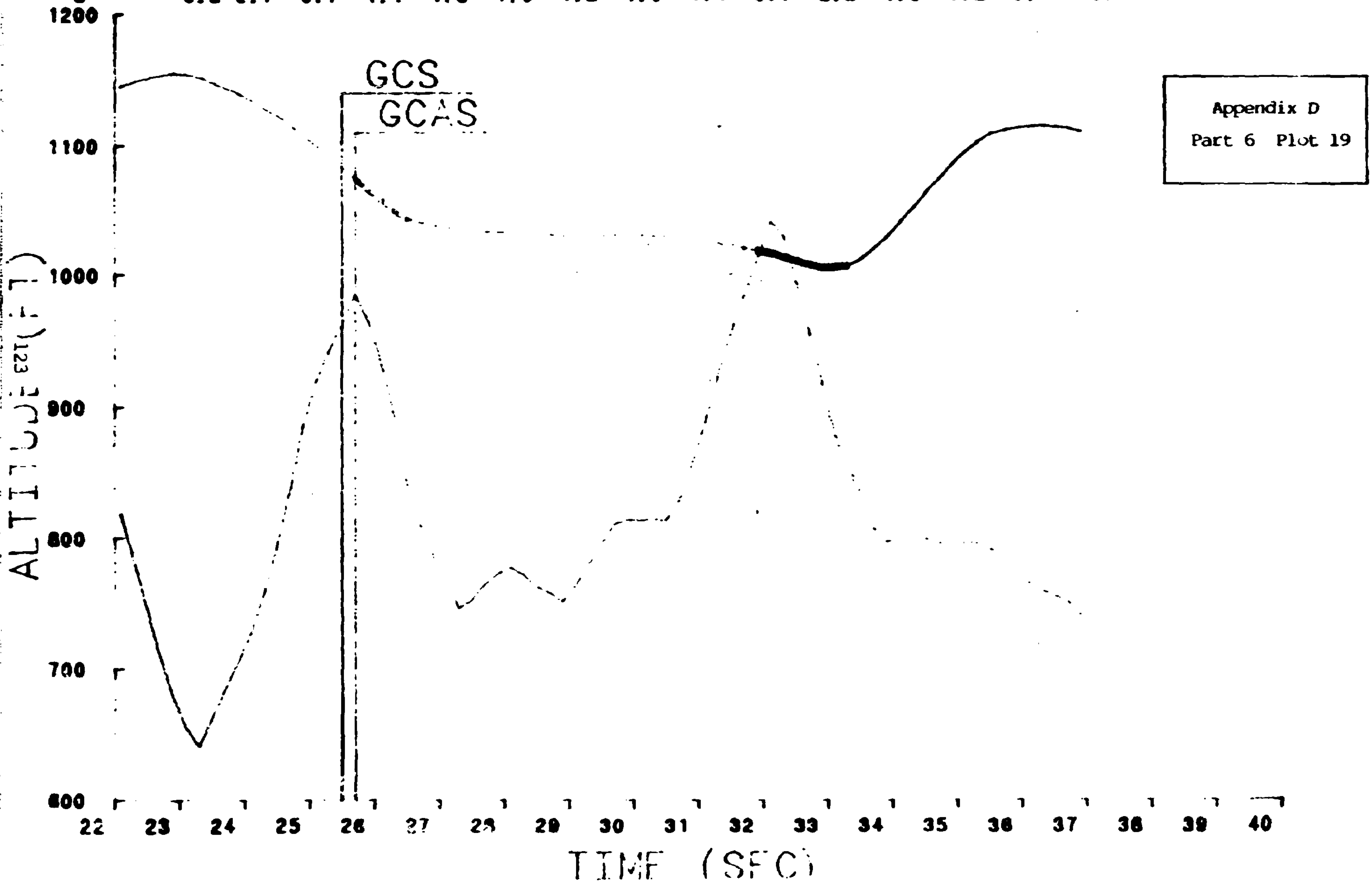


Appendix D
Part 6 Plot 18

GCAS MISSION 17 SUBJECT 6

EVENT #1

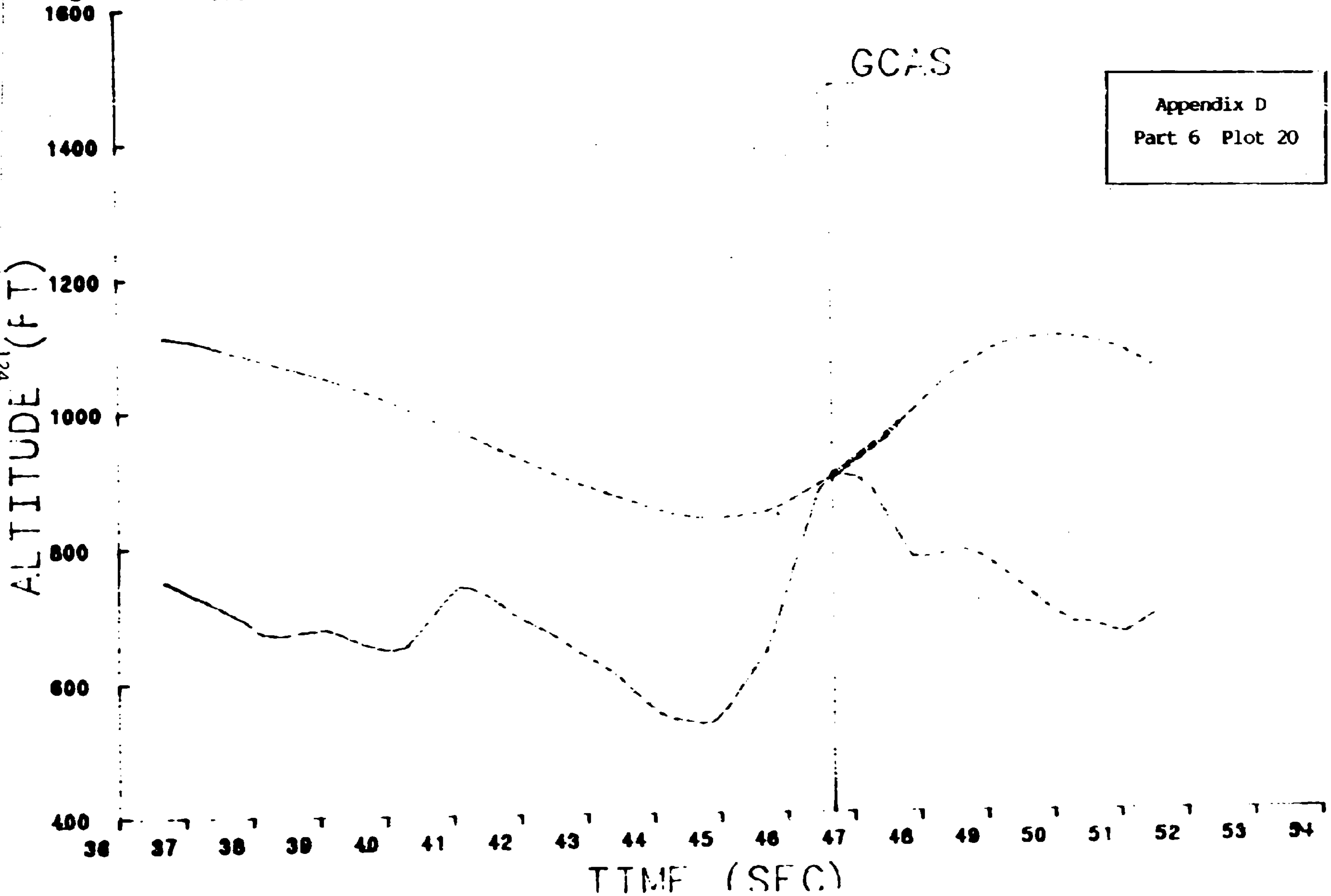
CAS	858	860	863	867	869	870	872	874	875	877	878	877	876	875	877
FPA	0	-2	-3	-3	-1	0	0	0	0	-1	0	3	4	1	-1
ROLL	-3	-3	-3	2	-1	-1	4	7	7	3	0	0	0	-1	-1
G	-0.3	0.7	0.7	1.1	1.3	1.0	1.2	1.0	1.1	0.7	2.2	1.8	0.2	0.4	-0.1



GCAS MISSION 17 SUBJECT 6

EVENT #2

CAS	878	880	883	885	888	890	892	894	893	891	889	886	882	882	883
FPA	−2	−2	−2	−3	−3	−3	−2	−1	1	4	5	5	2	−1	−4
ROLL	−1	−2	−3	−4	−6	−6	−6	−7	−10	−15	−22	−1	42	39	19
G	0.8	1.0	0.9	0.9	1.0	1.2	1.2	2.5	2.4	1.8	2.4	−0.4	−0.8	0.0	0.5



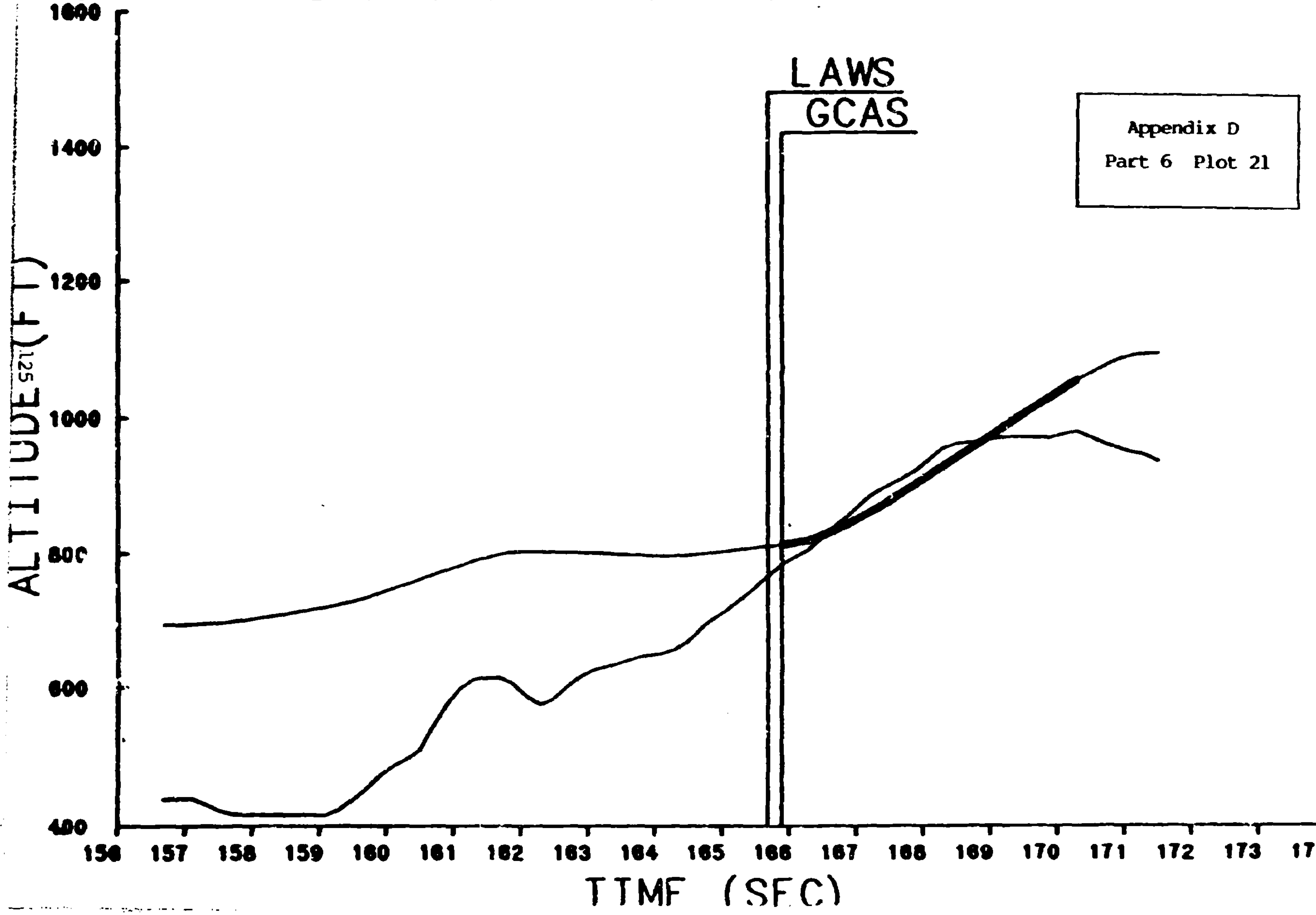
Appendix D

Part 6 Plot 20

GCAS MISSION 17 SUBJECT 6

EVENT #3

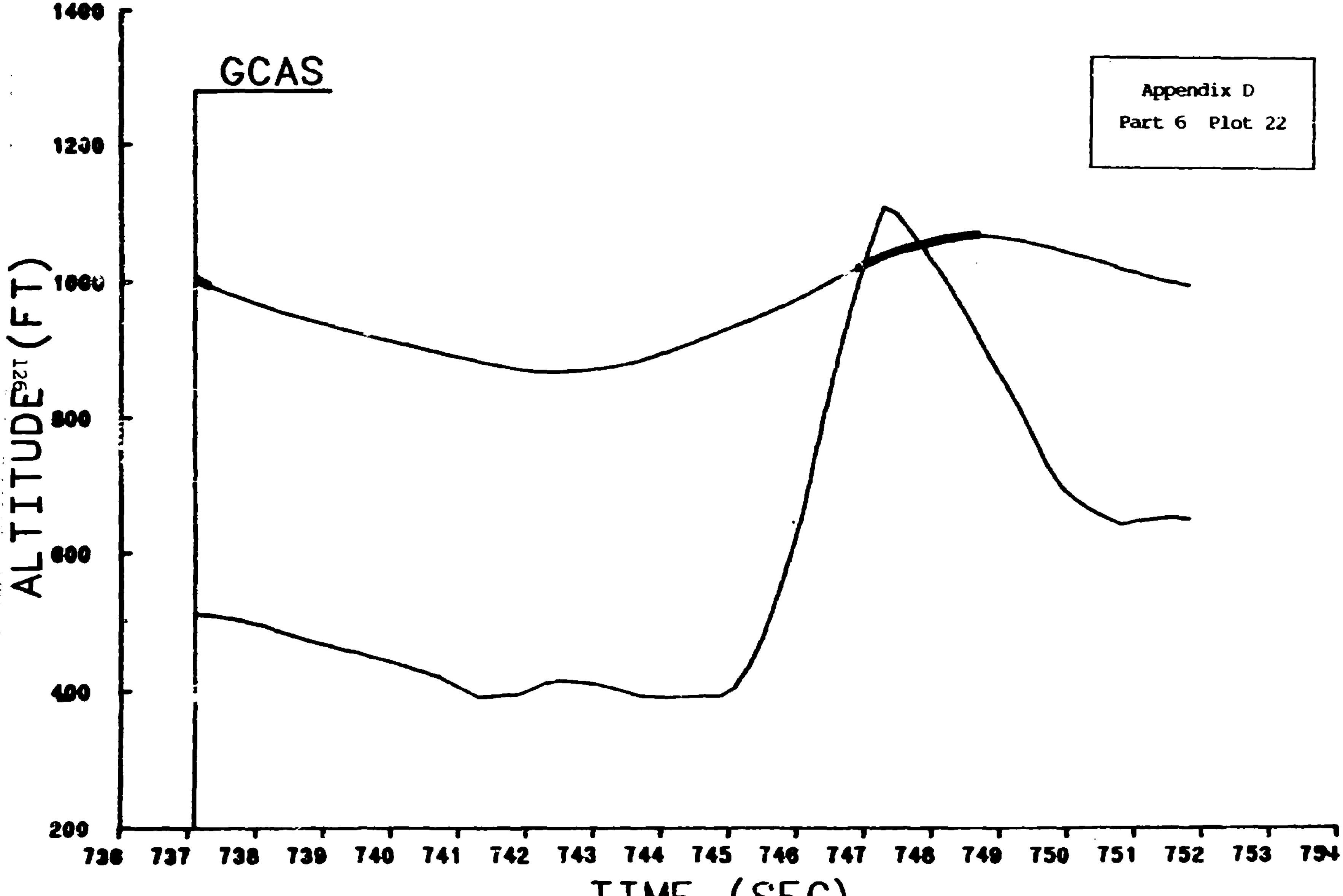
CAS	892	892	892	891	891	891	892	893	893	892	891	889	888	887	884
FPA	1	1	2	2	2	0	0	0	1	2	4	4	4	4	0
ROLL	2	−2	−5	−7	−9	−10	−10	−10	0	4	4	17	28	31	34
G	1.8	1.2	1.6	1.1	0.3	1.0	1.0	1.9	1.0	2.8	1.4	1.1	1.0	0.2	−0.8



GCAS MISSION 17 SUBJECT 6

EVENT #4

CAS	905	906	906	907	906	904	902	902	902	901	901	901	904	906	908
FFA	−2	−2	−2	−1	−1	1	2	3	3	3	1	−1	−2	−2	−1
ROLL	62	68	69	70	68	64	59	−5	−7	−1	10	23	15	7	2
G	3.2	3.1	3.0	2.9	4.1	3.9	2.8	1.3	2.1	0.9	0.9	−0.5	0.8	0.9	1.4

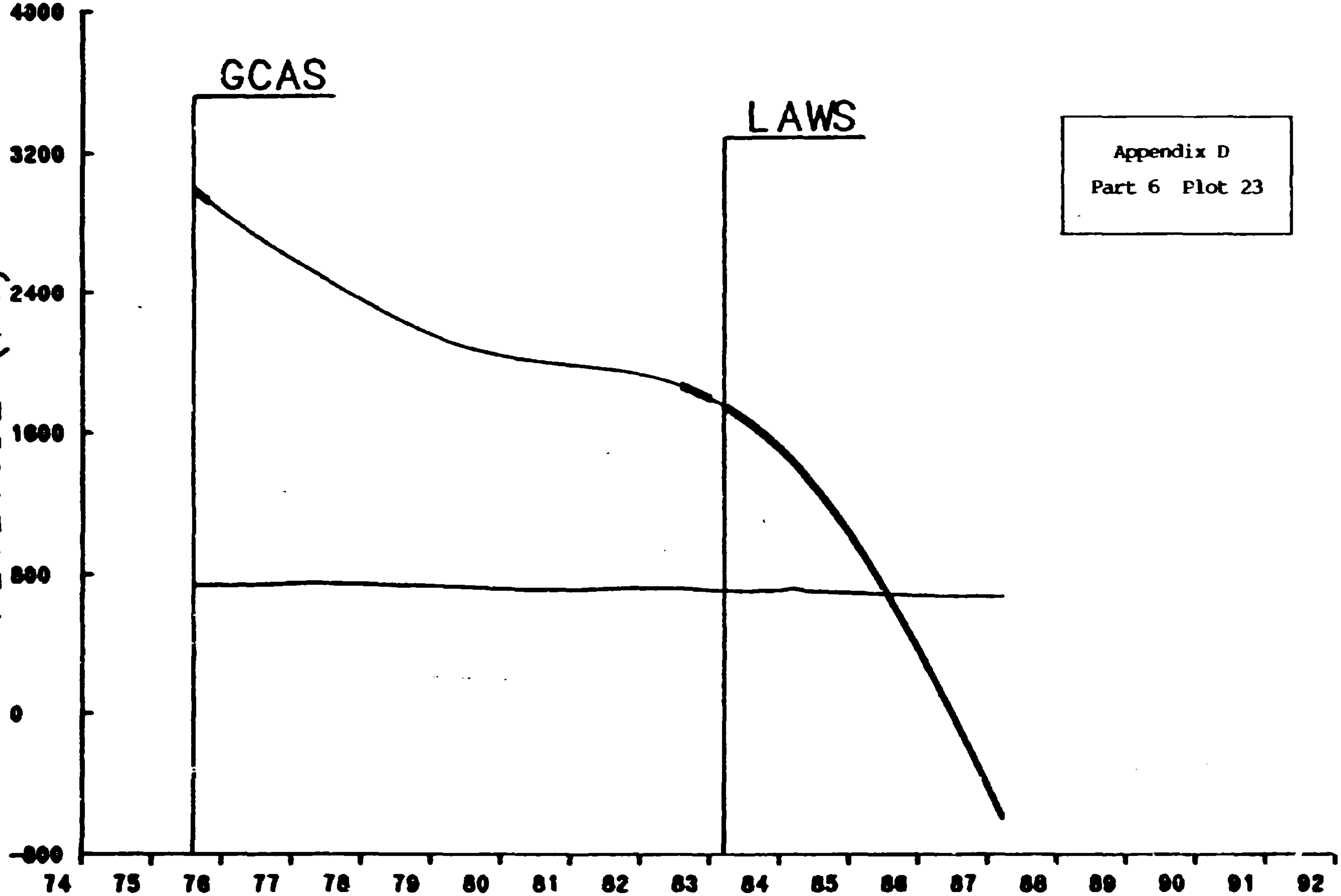


Appendix D
Part 6 Plot 22

GCAS MISSION 17 SUBJECT 7

EVENT #1

CAS	748	761	776	784	790	797	804	813	817	818	818
FPA	−22	−19	−16	−10	−4	−4	−9	−19	−34	−53	−72
ROLL	34	51	16	−4	1	102	170	−179	−173	−171	−147
G	4.0	3.4	2.7	4.4	2.6	1.2	2.5	4.4	7.1	8.1	8.1



Appendix D
Part 6 Plot 23

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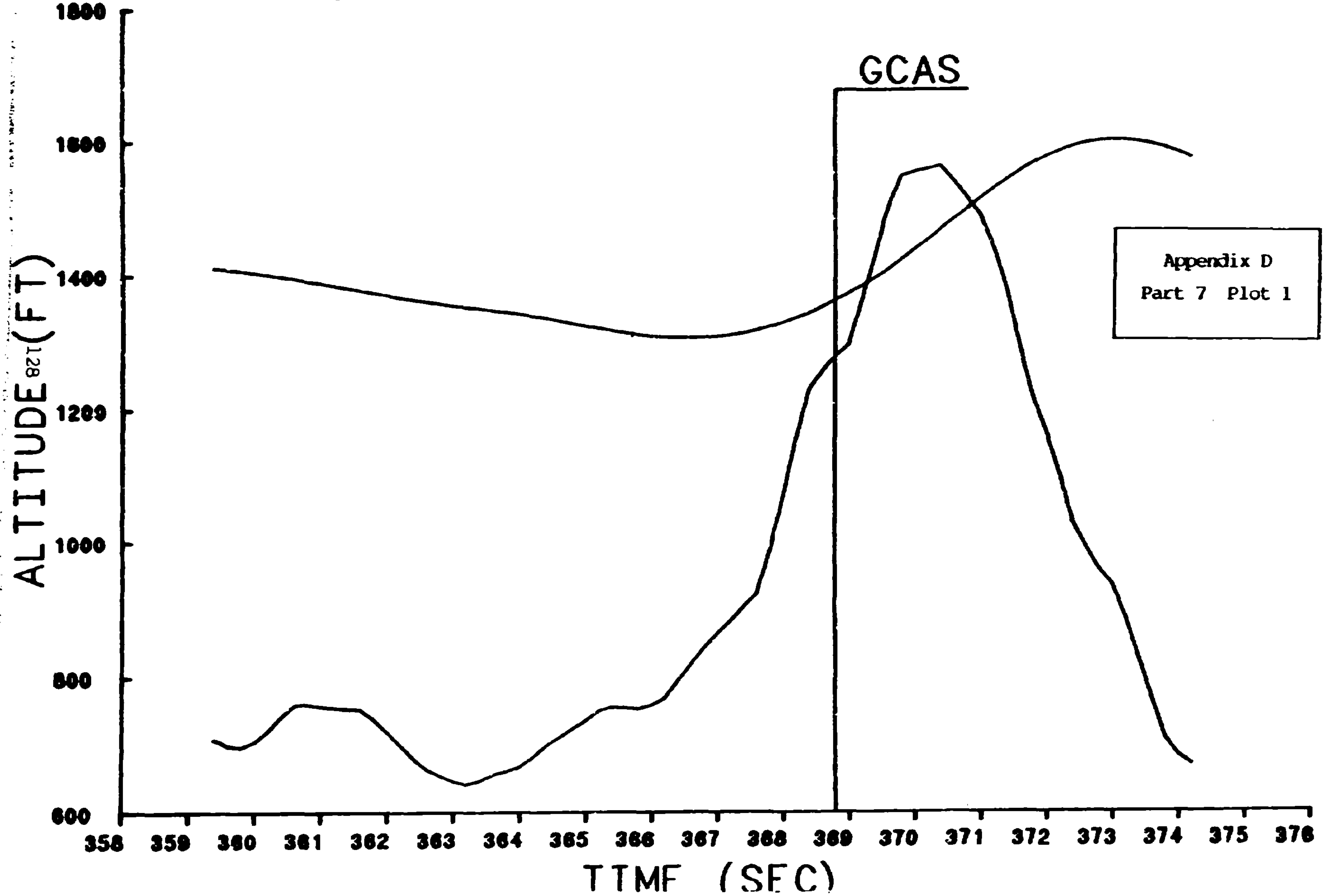
LAWS MISSION 15 SUBJECT 1

EVENT #1

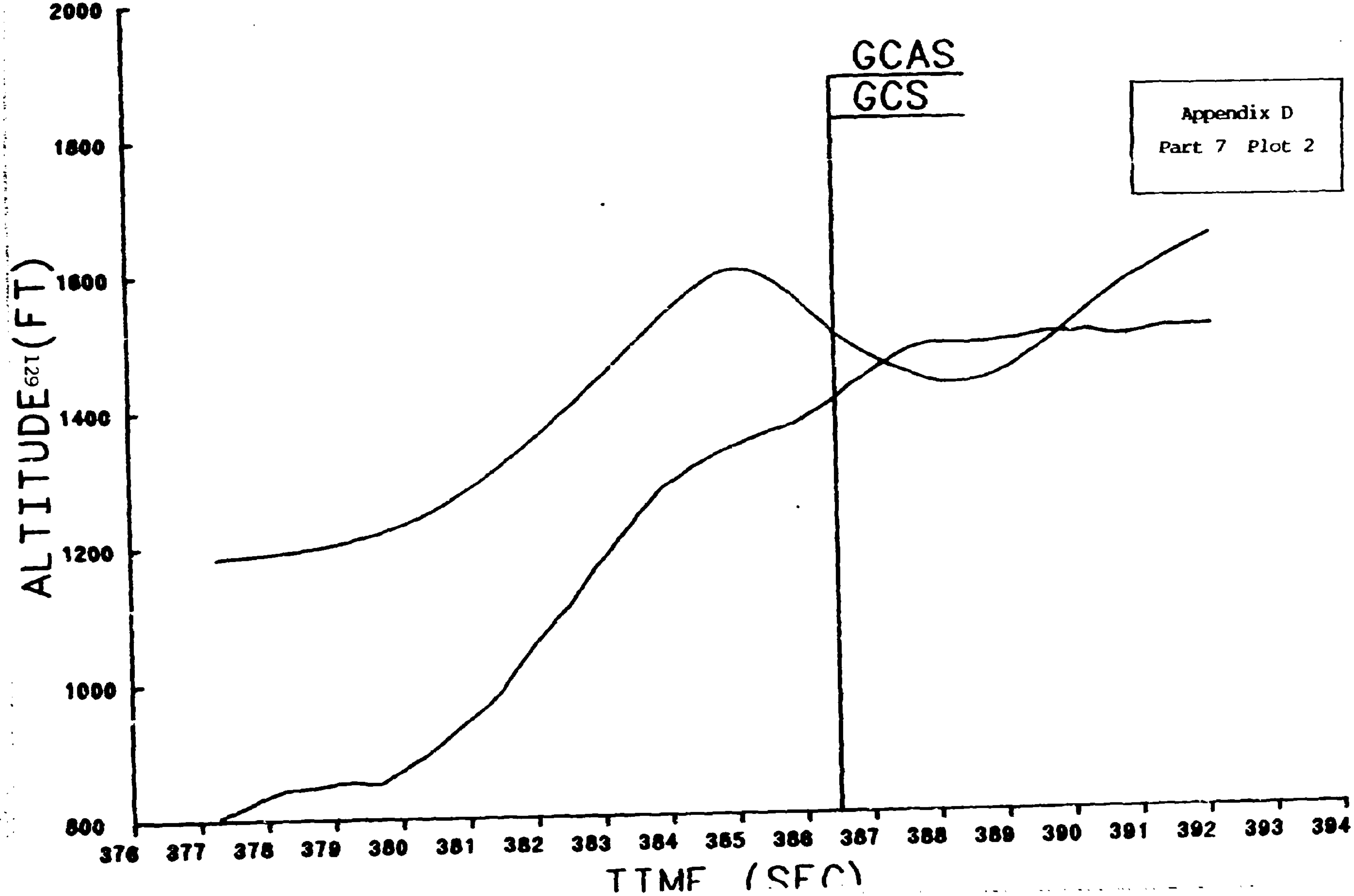
CAS	872	869	867	863	861	859	856	853	849	845	842	835	832	829	827
FPA	-1	-1	-1	-1	-1	-1	0	1	2	4	5	5	3	0	-3
ROLL	-62	-60	-59	-57	-62	-58	-48	-38	-35	-36	-38	-71	-97	-98	-94
G	1.6	2.0	2.2	1.9	1.6	1.8	2.1	2.4	2.0	2.0	1.6	1.1	1.9	2.3	2.4



LAWS MISSION 15 SUBJECT 3

EVENT #1

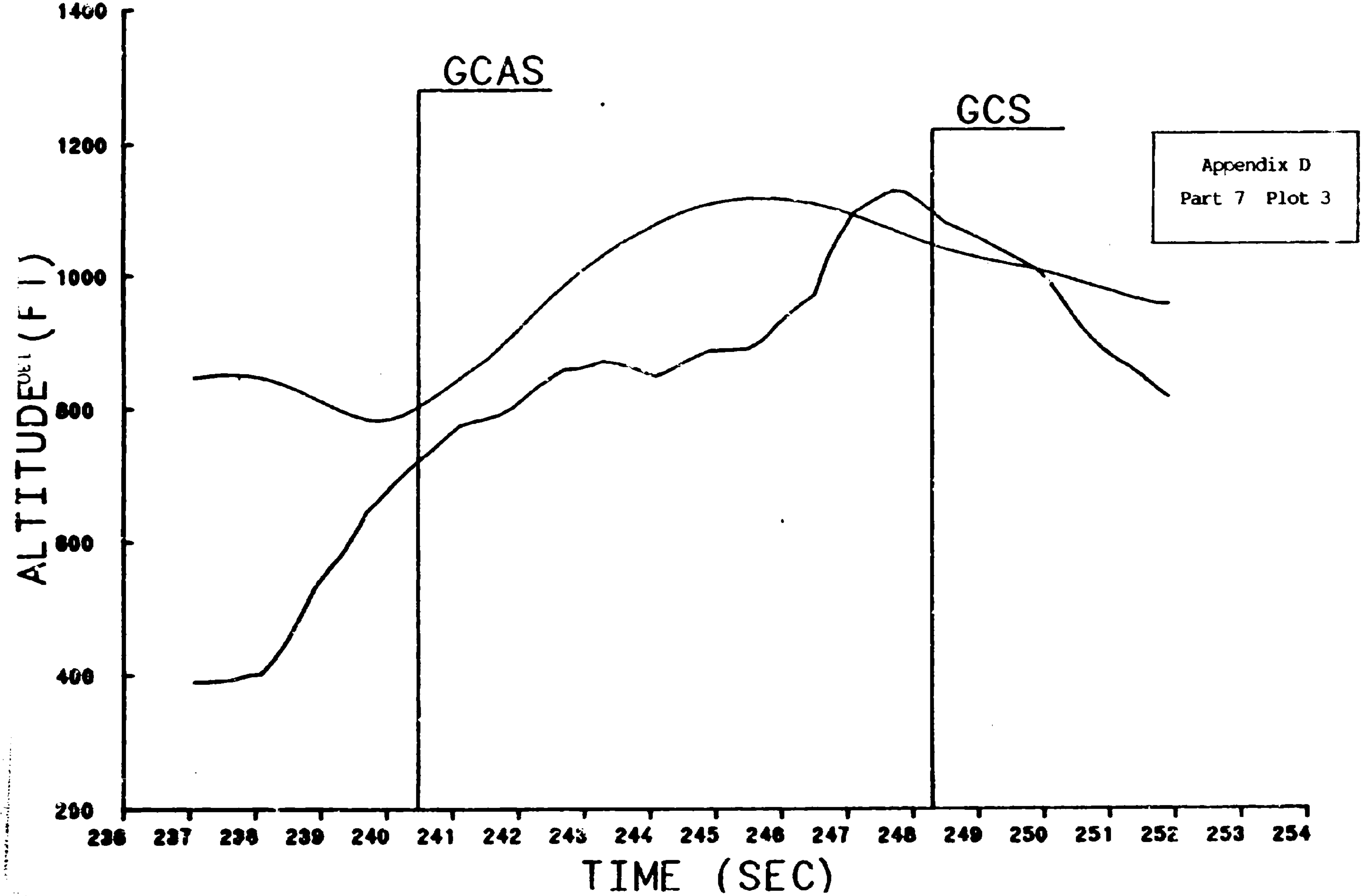
CAS	824	809	801	796	790	787	785	783	785	793	797	797	798	800	803
FPA	1	1	3	5	6	7	6	0	-7	-4	-1	4	6	4	3
ROLL	-78	-78	-88	-66	-88	-70	-88	-162	-83	-30	-24	-13	-19	-12	-6
G	5.7	5.4	4.9	4.5	3.8	3.5	2.5	3.7	2.0	2.4	3.5	3.4	1.2	0.4	0.8



LAWS MISSION 15 SUBJECT 5

EVENT #1

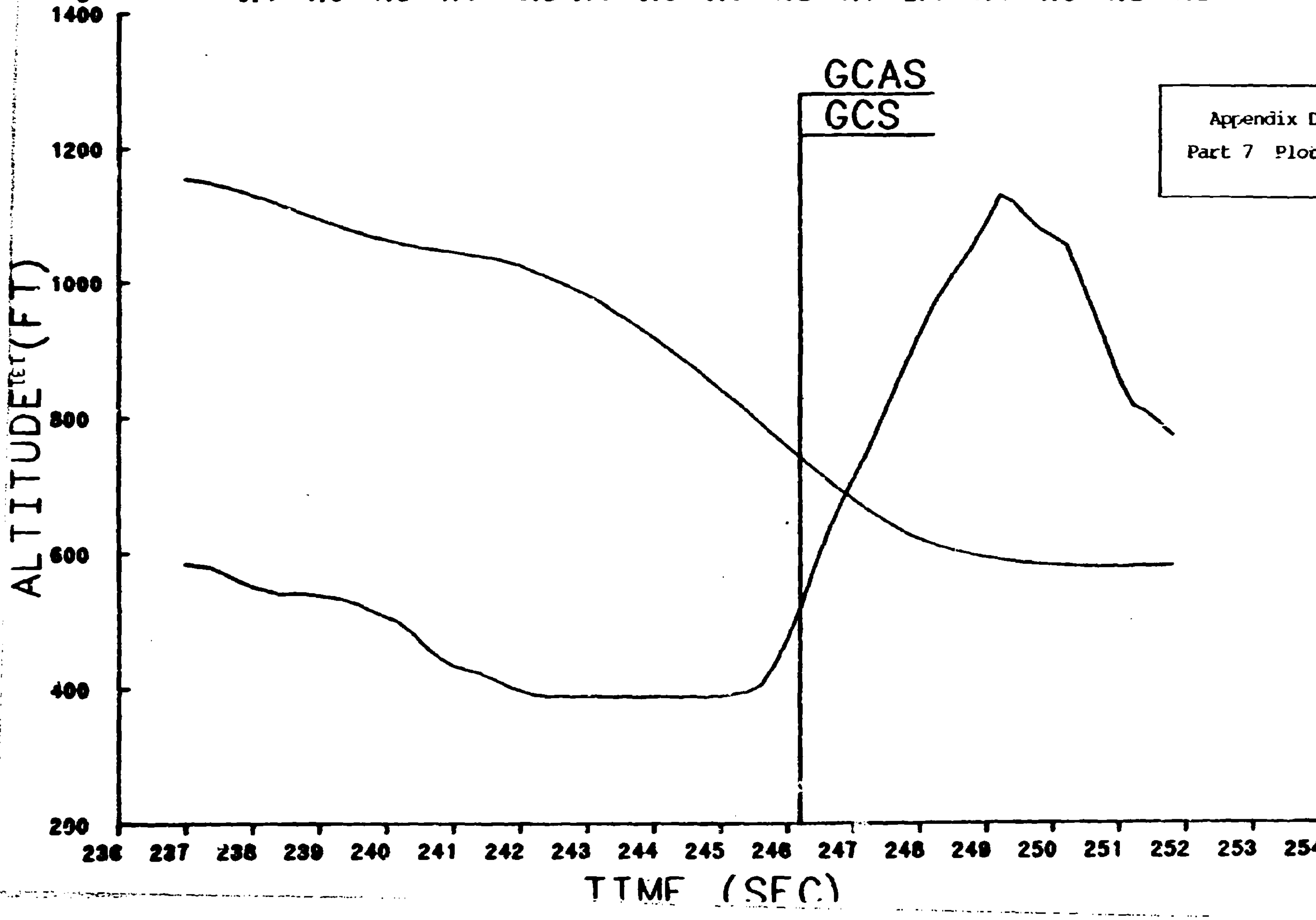
CAS	808	808	802	793	788	784	781	779	778	778	778	778	779	780	780
FPA	-1	-3	0	5	7	6	4	2	0	-2	-3	-2	-2	-2	0
ROLL	-150	-71	-28	-25	-27	-30	-30	-99	-85	-80	-65	-41	-37	-19	1
G	0.3	1.1	5.1	1.8	2.5	-0.0	0.5	0.2	1.9	2.3	2.5	1.7	0.6	1.1	2.3



LAWS MISSION 15 SUBJECT 7

EVENT #1

CAS	930	931	932	933	933	935	937	939	941	943	944	944	944	943	943
FPA	-2	-2	-2	-1	-2	-3	-4	-5	-5	-5	-3	-1	-1	0	0
ROLL	-20	-14	-2	6	6	8	9	9	5	3	3	2	2	2	2
G	0.4	1.3	1.5	1.1	-0.2	0.4	0.6	0.8	1.2	1.7	2.4	1.4	1.3	1.2	1.2

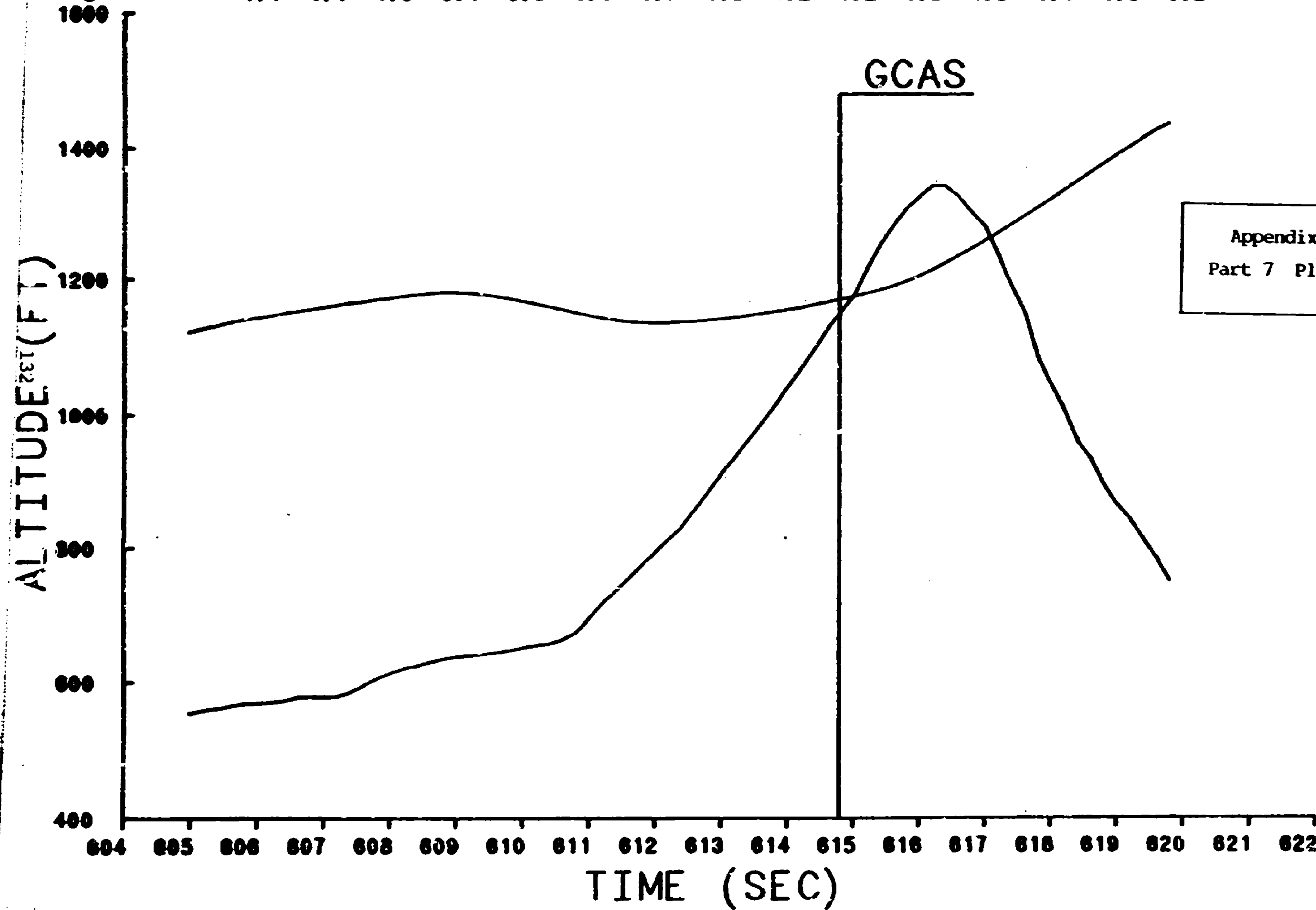


Appendix D
Part 7 Plot 4

LAWS MISSION 15 SUBJECT 7

EVENT #2

CAS	910	910	911	912	913	915	916	916	917	917	917	916	914	913	912
FPA	1	1	1	0	−1	−1	0	1	1	1	2	4	4	4	3
ROLL	48	36	14	−3	11	21	19	9	−2	−4	−2	1	1	−1	−4
G	1.1	1.1	1.0	0.1	0.6	1.1	1.7	1.3	1.2	1.2	1.9	1.3	1.1	1.0	0.2

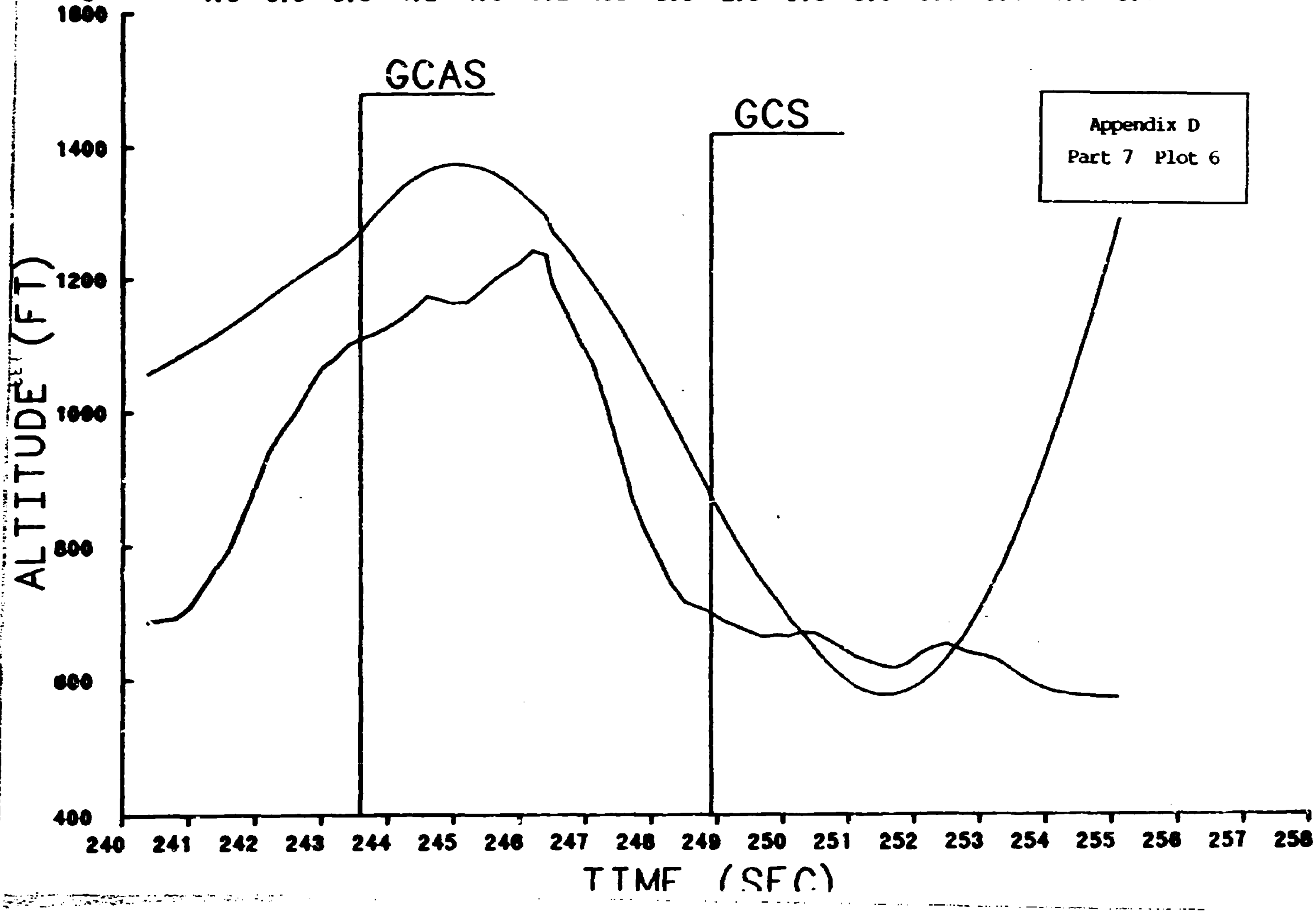


Appendix D
Part 7 Plot 5

LAWS MISSION 15 SUBJECT 8

EVENT #1

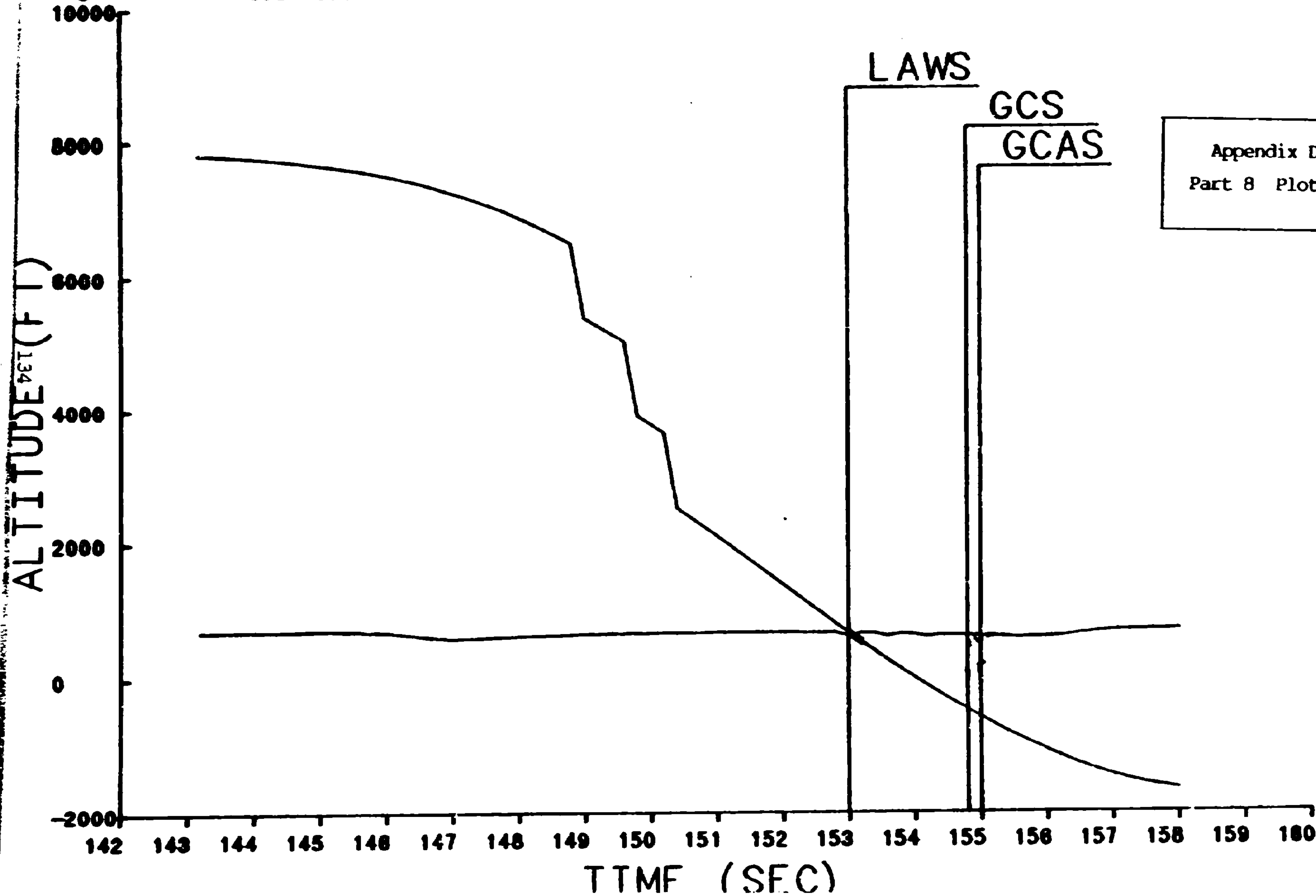
QAS	916	913	906	897	889	883	880	881	887	892	893	882	868	853	838
FPA	4	5	5	6	-1	-6	-9	-12	-11	-8	-4	4	12	19	26
ROLL	16	73	45	115	113	101	96	87	6	-38	-29	-29	-28	-26	-20
G	1.3	3.3	3.8	4.2	4.6	5.2	4.9	3.3	2.3	2.8	5.0	5.8	5.1	4.5	3.1



LAWS MISSION 16 SUBJECT 2

EVENT #1

CAS	629	637	645	655	660	674	687	701	723	740	752	761	765	764	753
FPA	-7	-12	-18	-27	-40	-55	-69	-83	-84	-72	-59	-47	-35	-23	-10
ROLL	-128	-178	-179	-179	179	174	169	-28	-2	-5	-4	-3	-2	-1	-2
G	0.5	0.6	1.4	3.2	4.2	4.8	4.9	4.9	5.0	5.6	5.8	5.7	5.5	6.4	6.6

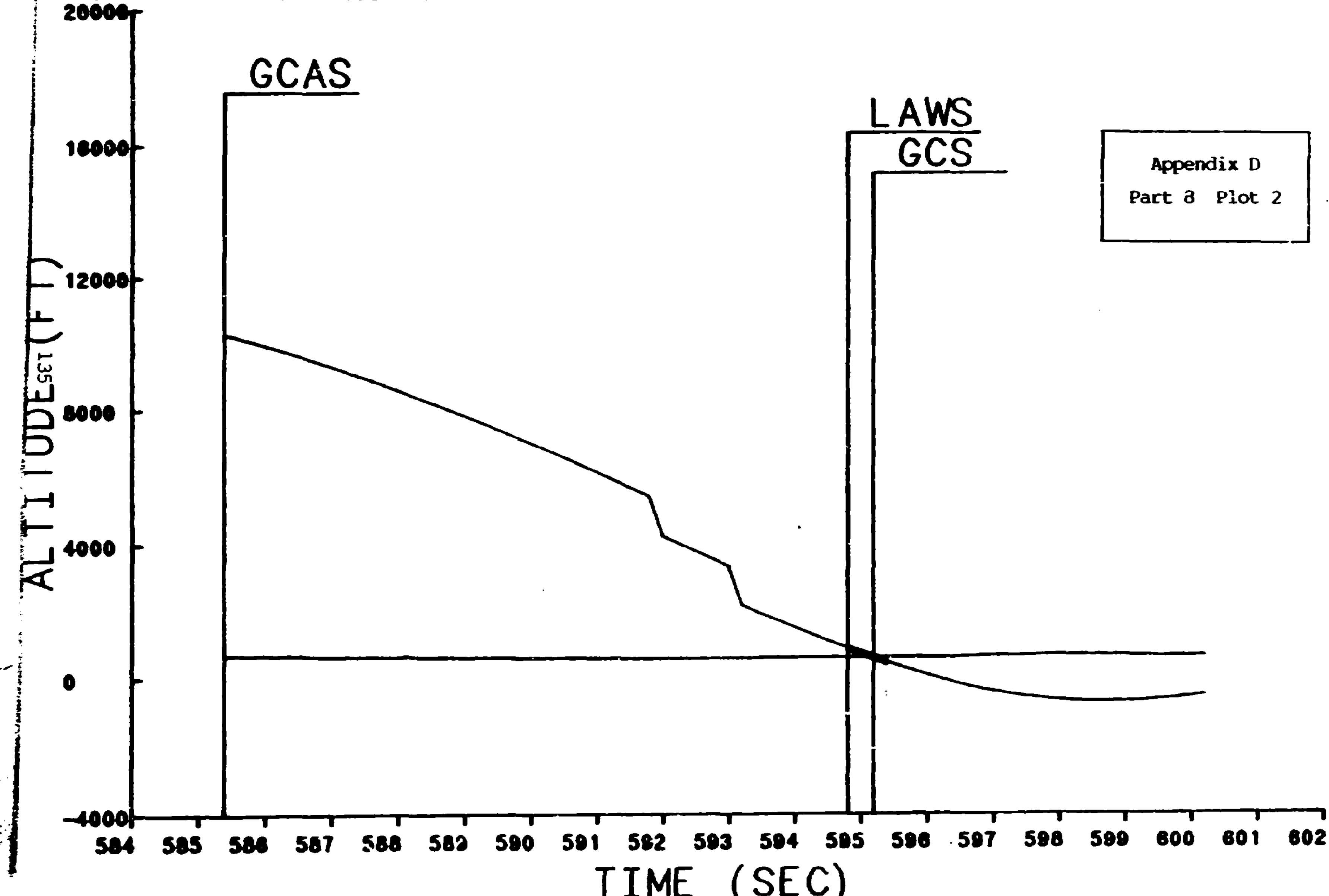


Appendix D
Part 8 Plot 1

LAWS MISSION 16 SUBJECT 2

EVENT #2

CAS	801	822	843	864	886	899	923	930	933	932	929	909	879	856	807
FPA	-48	-56	-63	-69	-74	-77	-76	-69	-59	-48	-39	-23	-9	7	19
ROLL	-151	-146	-139	-128	-109	-82	-52	-35	-28	-30	-25	-4	-29	-26	-29
G	3.1	3.2	3.1	3.0	3.2	3.9	5.7	7.0	7.0	6.6	8.3	9.0	9.4	8.3	7.7

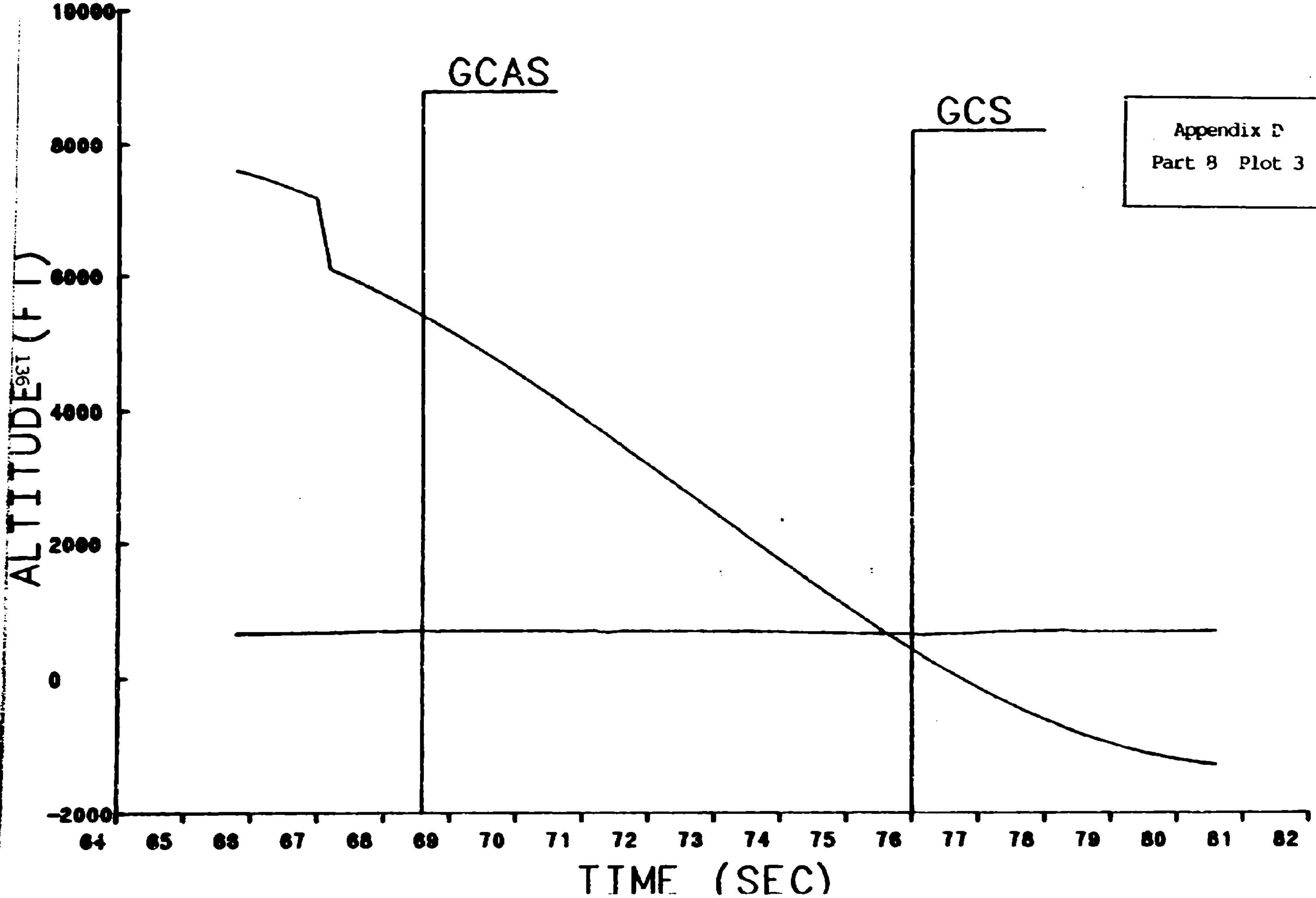


Appendix D
Part 8 Plot 2

LAWS MISSION 16 SUBJECT 4

EVENT #1

CAS	540	579	609	635	675	709	744	775	793	830	851	864	878	885	886
FPA	-42	-53	-64	-75	-85	-85	-76	-68	-59	-50	-41	-32	-24	-15	-7
ROLL	179	178	175	167	43	9	5	3	3	2	1	1	0	0	-1
G	2.4	2.8	3.2	3.3	3.5	3.5	3.7	4.1	4.2	4.6	5.0	5.2	5.0	5.0	5.1

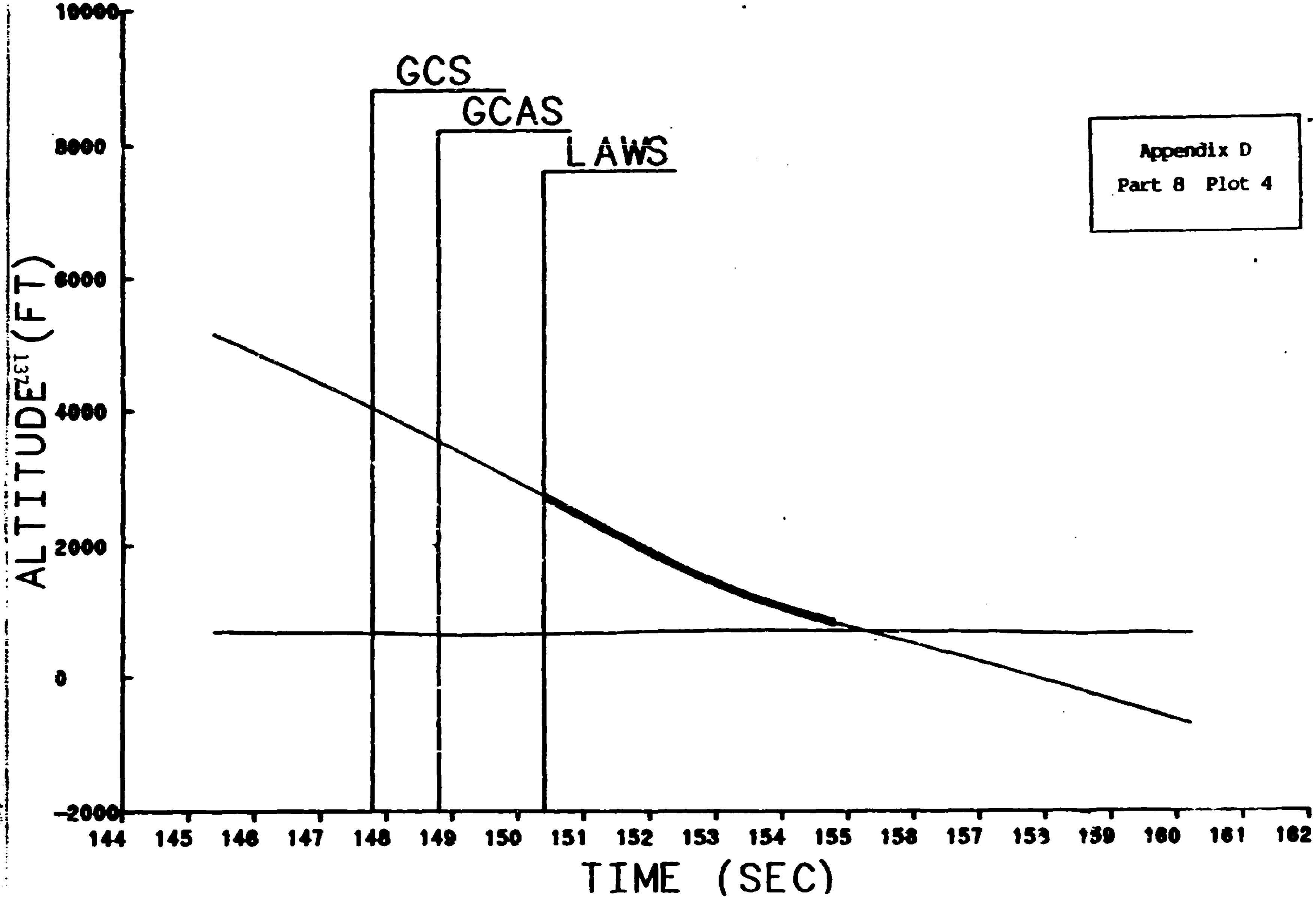


Appendix D
Part B Plot 3

LAWS MISSION 16 SUBJECT 4

EVENT #2

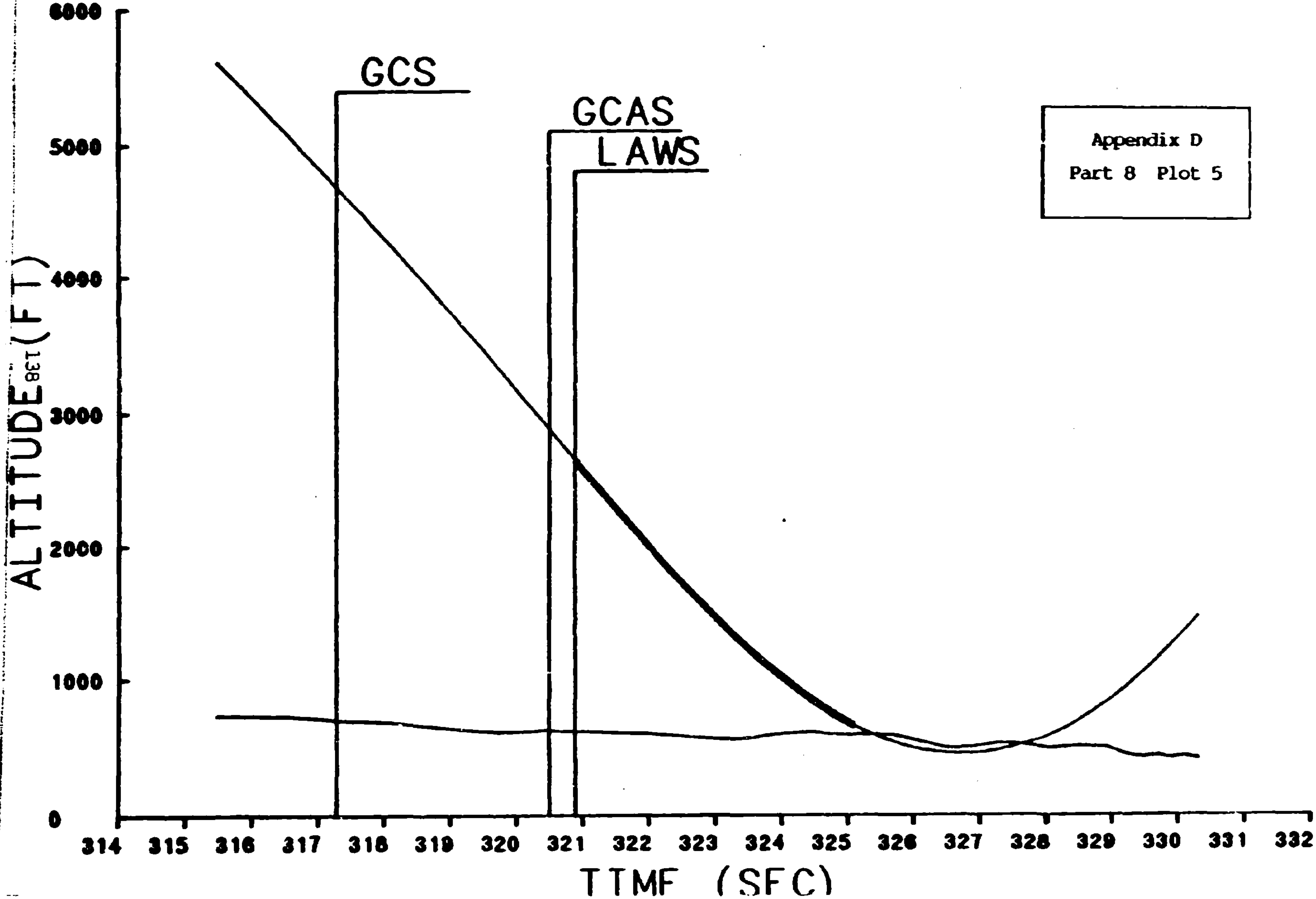
CAS	637	659	681	702	714	742	759	772	787	803	820	836	848	867	882
FPA	−45	−45	−45	−45	−45	−45	−41	−32	−23	−19	−20	−20	−20	−20	−21
ROLL	0	0	0	0	0	−1	−2	−2	−3	−2	−2	−2	−2	−2	−2
G	0.8	0.5	0.8	0.7	0.7	0.7	3.8	4.9	4.0	0.7	1.3	0.9	0.9	0.8	0.8



LAWS MISSION 16 SUBJECT 4

EVENT #3

CAS	712	750	780	809	837	853	887	904	913	917	915	909	893	879	838
FPA	-47	-46	-45	-44	-43	-43	-39	-32	-24	-14	-5	5	16	28	41
ROLL	3	2	2	2	1	1	1	0	-1	-1	-2	-3	-4	-5	-6
G	-0.2	1.0	1.0	1.1	1.1	1.2	3.5	4.7	5.1	5.9	5.3	5.8	6.7	6.8	7.1

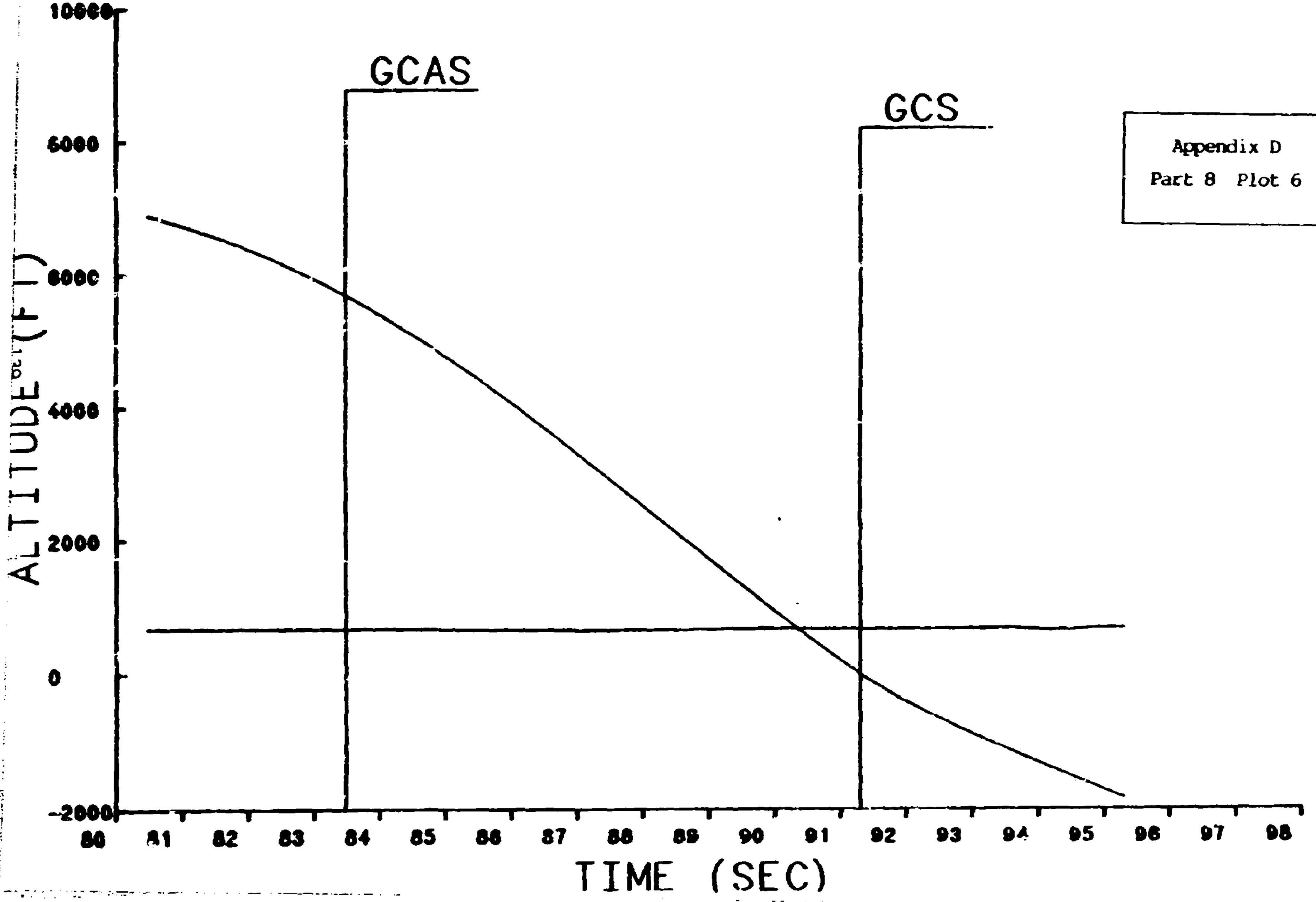


Appendix D
Part 8 Plot 5

LAWS MISSION 16 SUBJECT 5

EVENT #1

CAS	603	629	658	688	721	753	787	819	849	874	888	892	906	923	937
FPA	-33	-42	-52	-62	-72	-83	-88	-79	-70	-60	-47	-33	-29	-26	-25
ROLL	-180	-180	179	179	-178	-164	-4	-2	-1	2	7	13	12	11	3
G	1.8	2.5	3.0	3.2	3.6	4.0	3.8	4.2	4.7	5.7	7.4	5.1	2.5	1.7	1.3



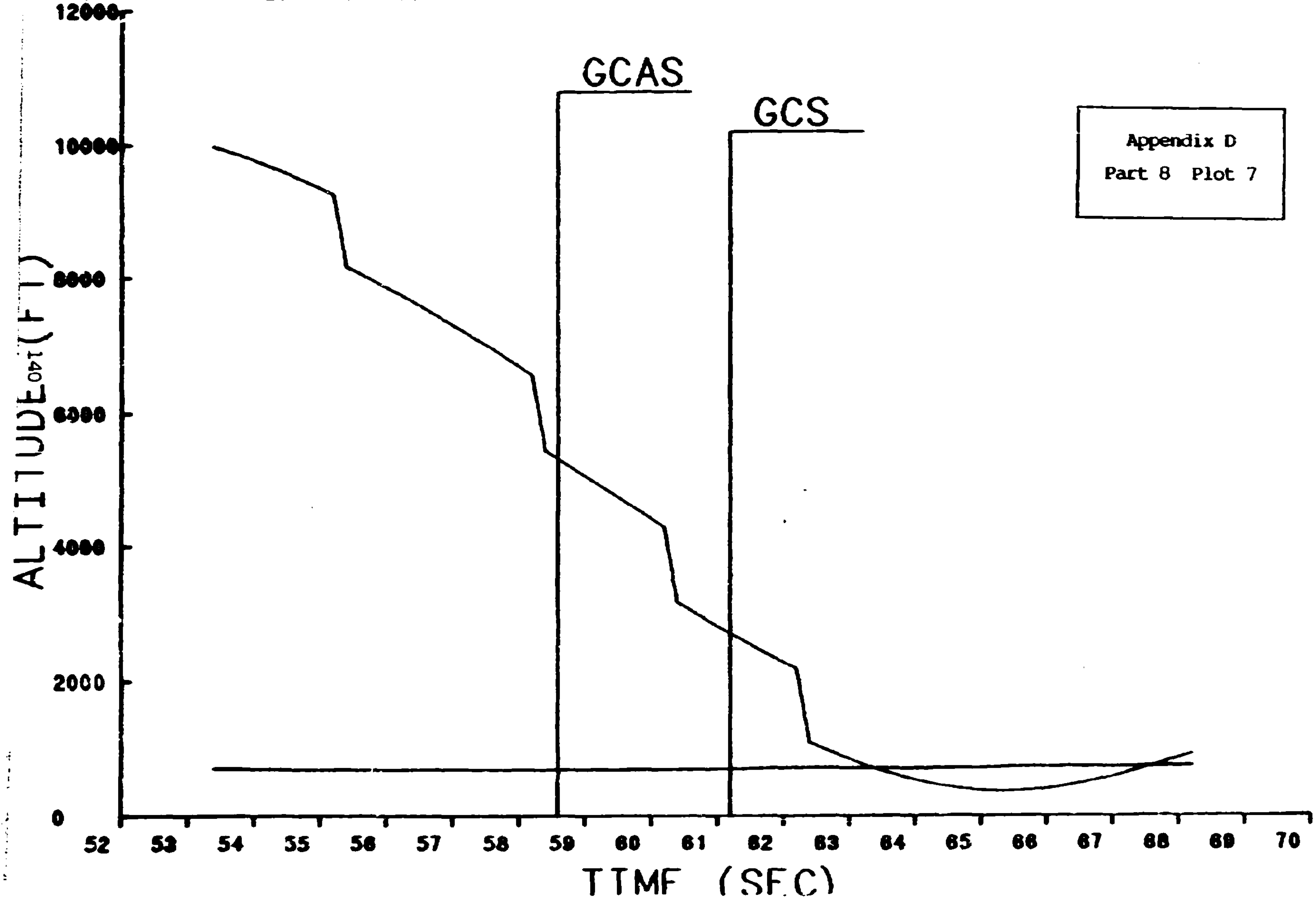
Appendix D

Part 8 Plot 6

LAWS MISSION 16 SUBJECT 7

EVENT #1

CAS	526	550	576	603	632	661	688	710	727	738	739	732	708	691	683
FPA	-47	-59	-71	-83	-86	-75	-64	-53	-41	-30	-17	-3	12	22	27
ROLL	175	180	179	5	1	0	0	-1	-1	-2	-3	-4	-6	-7	-8
G	2.7	3.0	3.4	3.6	3.9	4.1	4.4	5.1	5.0	5.9	6.1	6.4	6.8	3.6	2.3

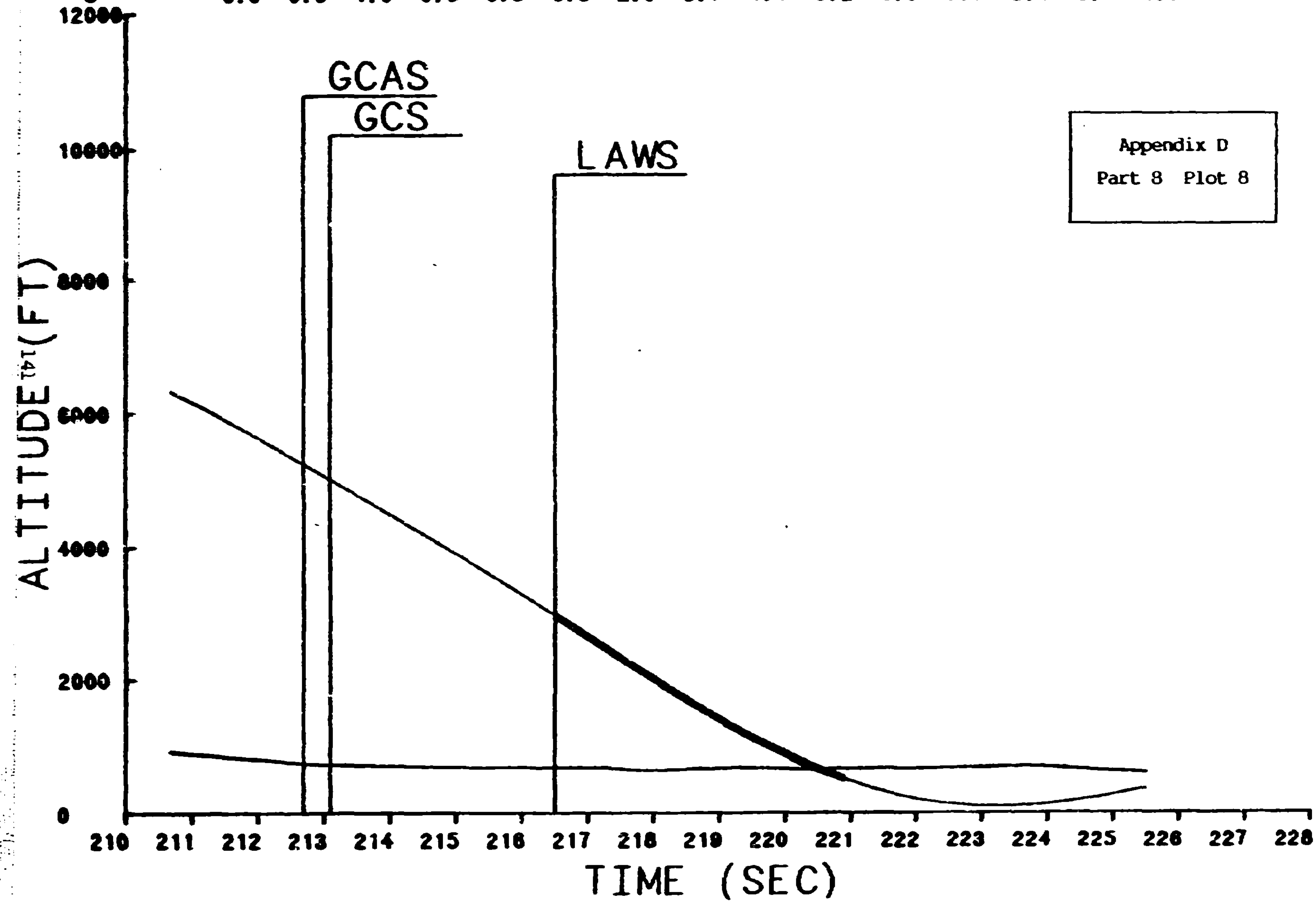


Appendix D
Part 8 Plot 7

LAWS MISSION 16 SUBJECT /

EVENT #2

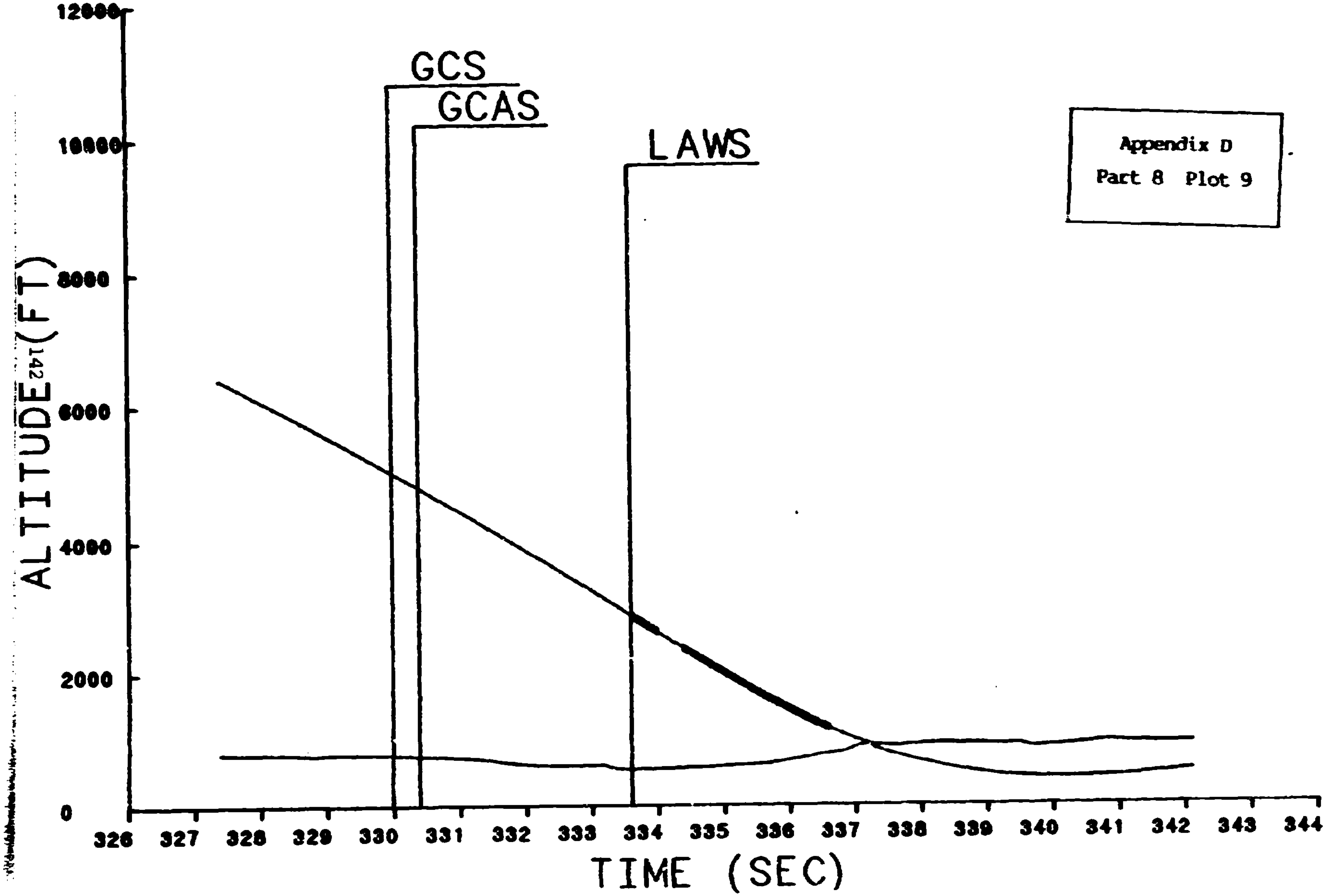
CAS	753	783	813	841	868	894	919	939	954	961	959	952	943	934	928
FPA	-45	-48	-48	-45	-45	-45	-44	-40	-33	-28	-17	-7	2	8	11
ROLL	2	2	1	1	1	0	-1	-1	-1	1	1	1	0	0	0
G	0.0	0.6	1.0	0.6	0.9	0.3	2.0	3.7	4.4	5.2	6.0	5.7	5.1	3.1	1.9



LAWS MISSION 16 SUBJECT 7

EVENT #3

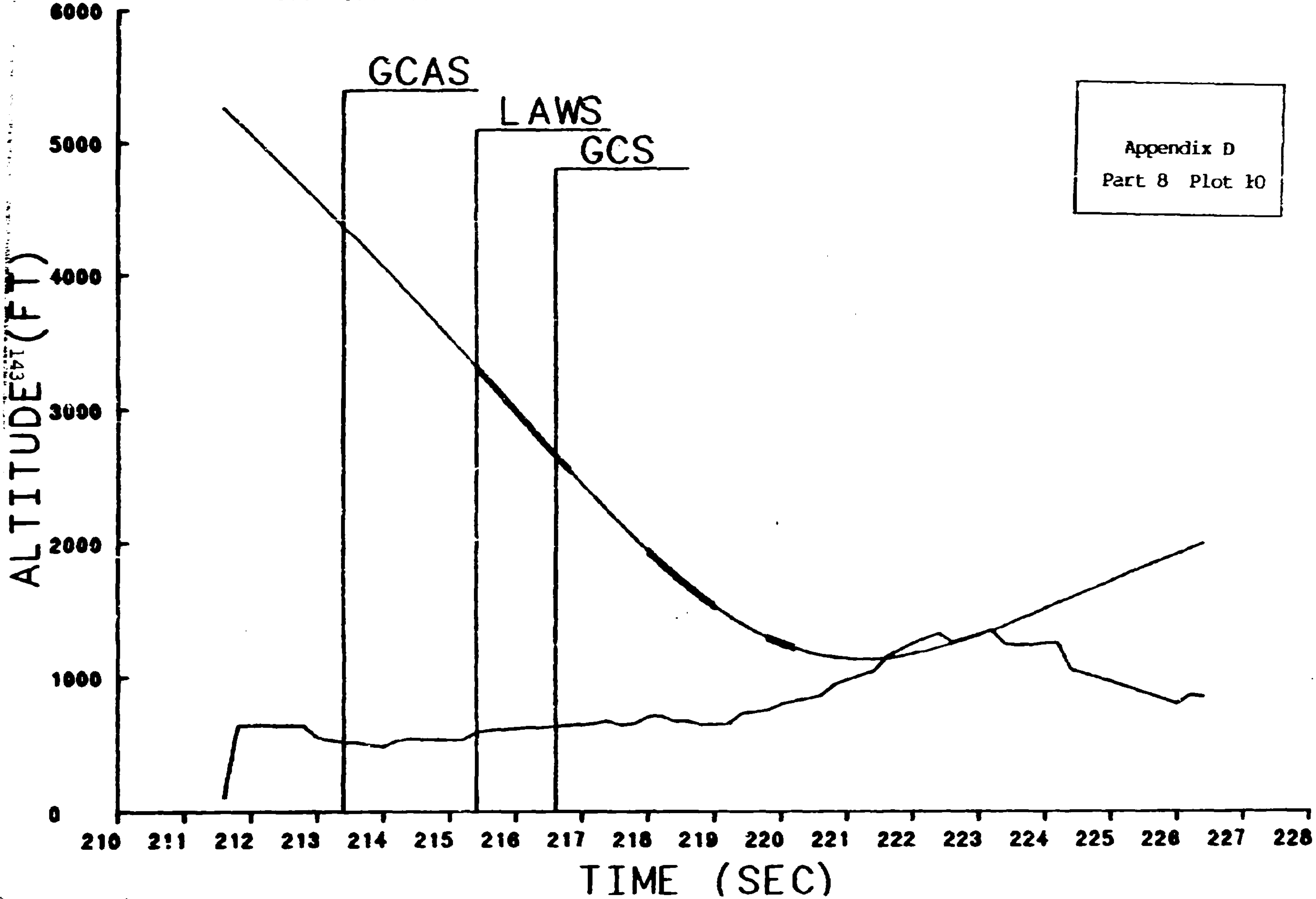
CAS	735	766	795	824	852	878	904	926	938	942	943	943	940	937	934
FPA	-45	-45	-45	-45	-45	-45	-44	-41	-32	-23	-15	-7	-1	4	6
ROLL	-1	-1	-2	-2	-2	-1	-1	-1	0	1	0	-1	0	0	0
G	1.1	0.9	0.8	0.6	0.8	0.9	1.1	4.0	6.0	5.5	4.9	4.6	3.9	2.4	1.7



LAWS MISSION 16 SUBJECT 8

EVENT #1

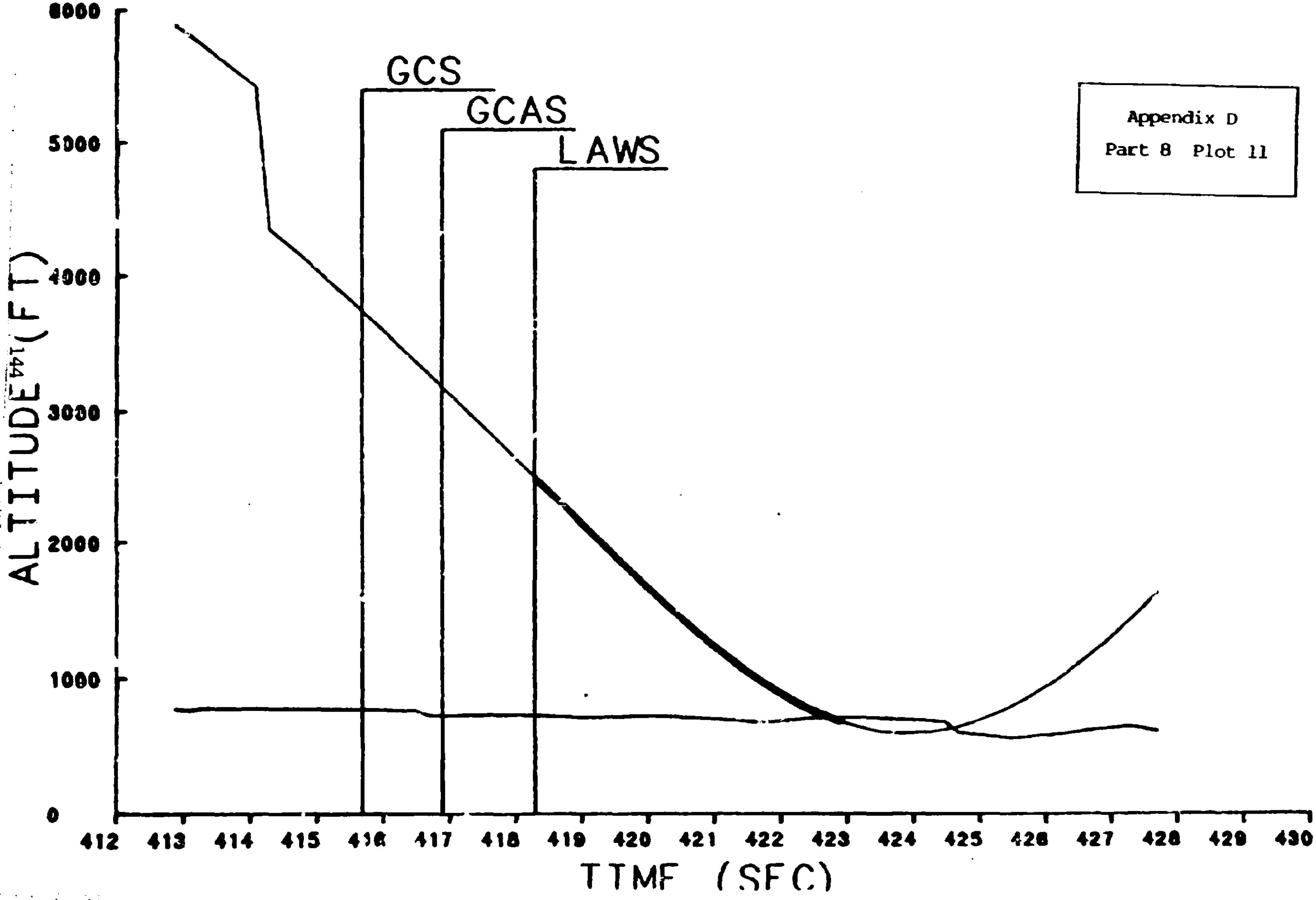
CAS	685	710	734	754	767	775	775	764	744	717	689	674	671	670	671
FPA	-47	-47	-47	-46	-46	-42	-34	-23	-11	1	11	17	18	17	16
ROLL	0	-1	-1	-1	-1	-1	-2	-3	-3	-4	-5	-3	1	1	1
G	0.9	0.8	0.8	0.7	1.0	3.2	5.0	5.7	5.9	6.0	4.3	2.5	0.6	0.2	-0.1



LAWS MISSION 16 SUBJECT 8

EVENT #2

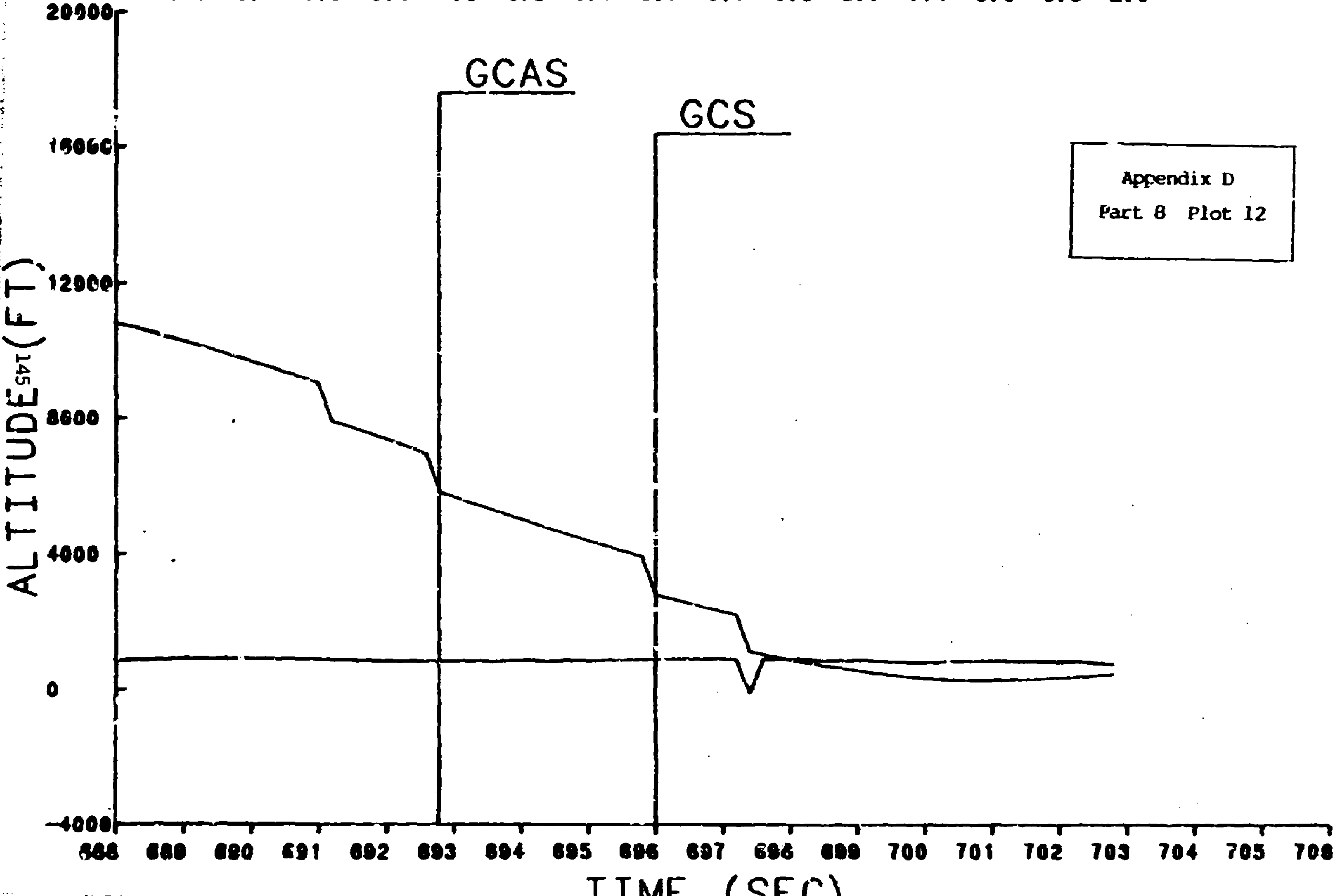
CAS	564	598	631	664	696	728	755	776	791	797	791	780	762	739	712
FPA	-44	-45	-45	-45	-45	-44	-40	-33	-25	-15	-3	9	21	32	44
ROLL	-3	-2	-2	-2	-2	-3	-4	-4	-4	-3	-3	-3	-3	-4	-4
G	0.1	0.4	0.7	0.9	1.0	1.0	3.2	3.9	4.8	5.7	6.3	6.1	5.7	5.5	5.3



LAWS MISSION 16 SUBJECT 8

EVENT #3

CAS	738	728	722	717	712	703	689	680	668	652	632	604	559	522	502
FPA	−48	−59	−68	−76	−76	−70	−62	−54	−45	−37	−29	−18	−2	10	16
ROLL	−118	−112	−91	−58	−40	−38	−38	−40	−41	−43	−44	−11	0	1	0
G	5.8	5.1	5.5	5.6	6.0	6.2	6.1	5.7	5.7	5.8	5.7	6.4	5.8	3.5	2.0

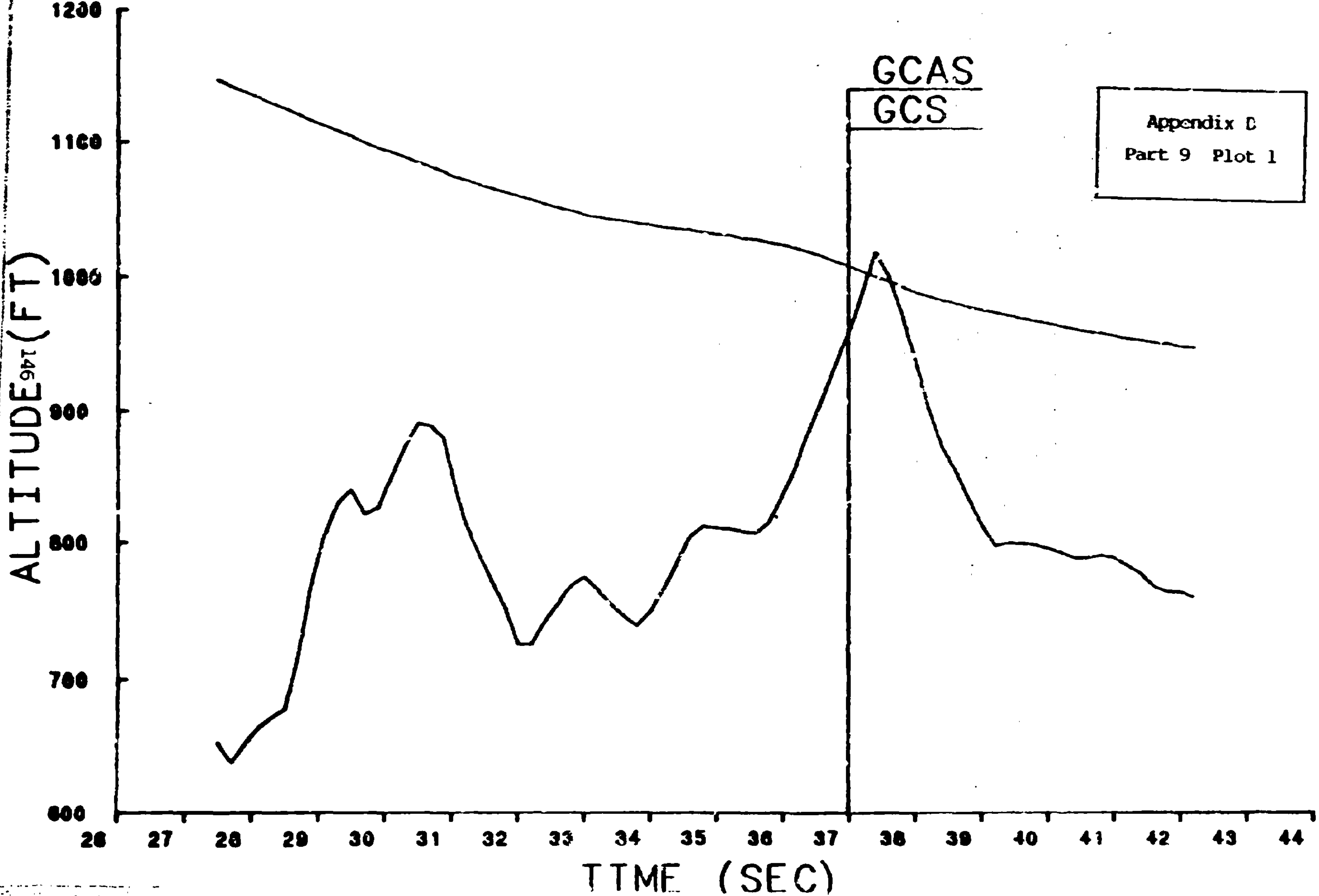


Appendix D
Part 8 Plot 12

LAWS MISSION 17 SUBJECT 1

EVENT #1

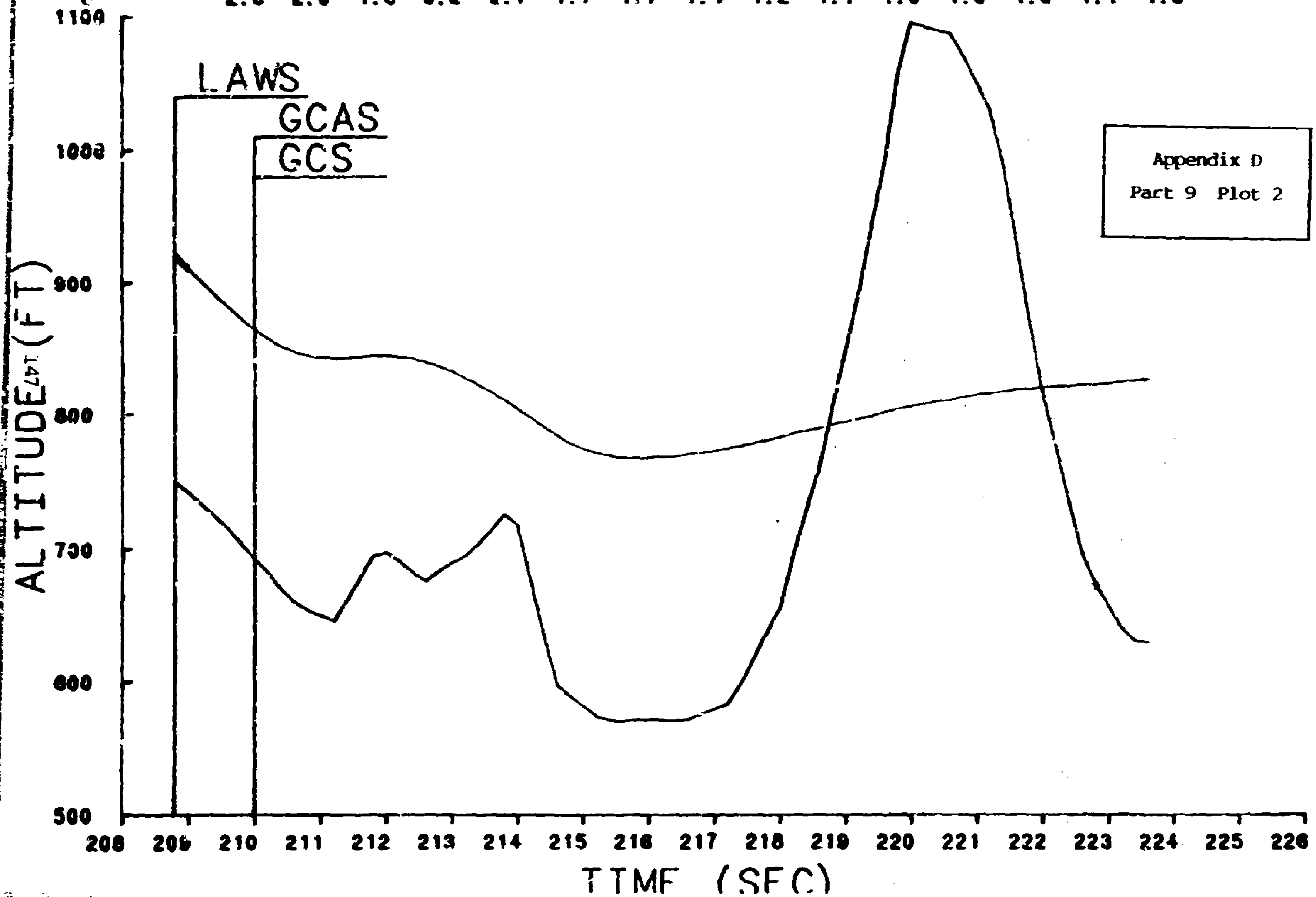
CAS	756	763	769	773	780	786	791	795	798	805	810	813	818	822	826
FPA	-2	-2	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
ROLL	3	2	1	0	0	1	1	1	4	[illegible]	0	0	2	2	2
G	1.0	1.1	1.1	1.1	1.1	1.2	1.1	0.9	0.7	0.9	1.2	1.1	1.0	1.0	1.0



LAWS MISSION 17 SUBJECT 1

EVENT #2

CAS	831	832	834	836	837	841	842	843	844	845	845	346	847	848	849
FPA	-3	-1	0	-1	-2	-2	0	0	1	1	1	1	0	0	1
ROLL	63	1	9	22	26	23	19	18	21	23	23	23	25	25	25
G	2.6	2.0	1.0	0.3	0.7	1.7	1.7	1.4	1.2	1.1	1.0	1.0	1.0	1.1	1.3

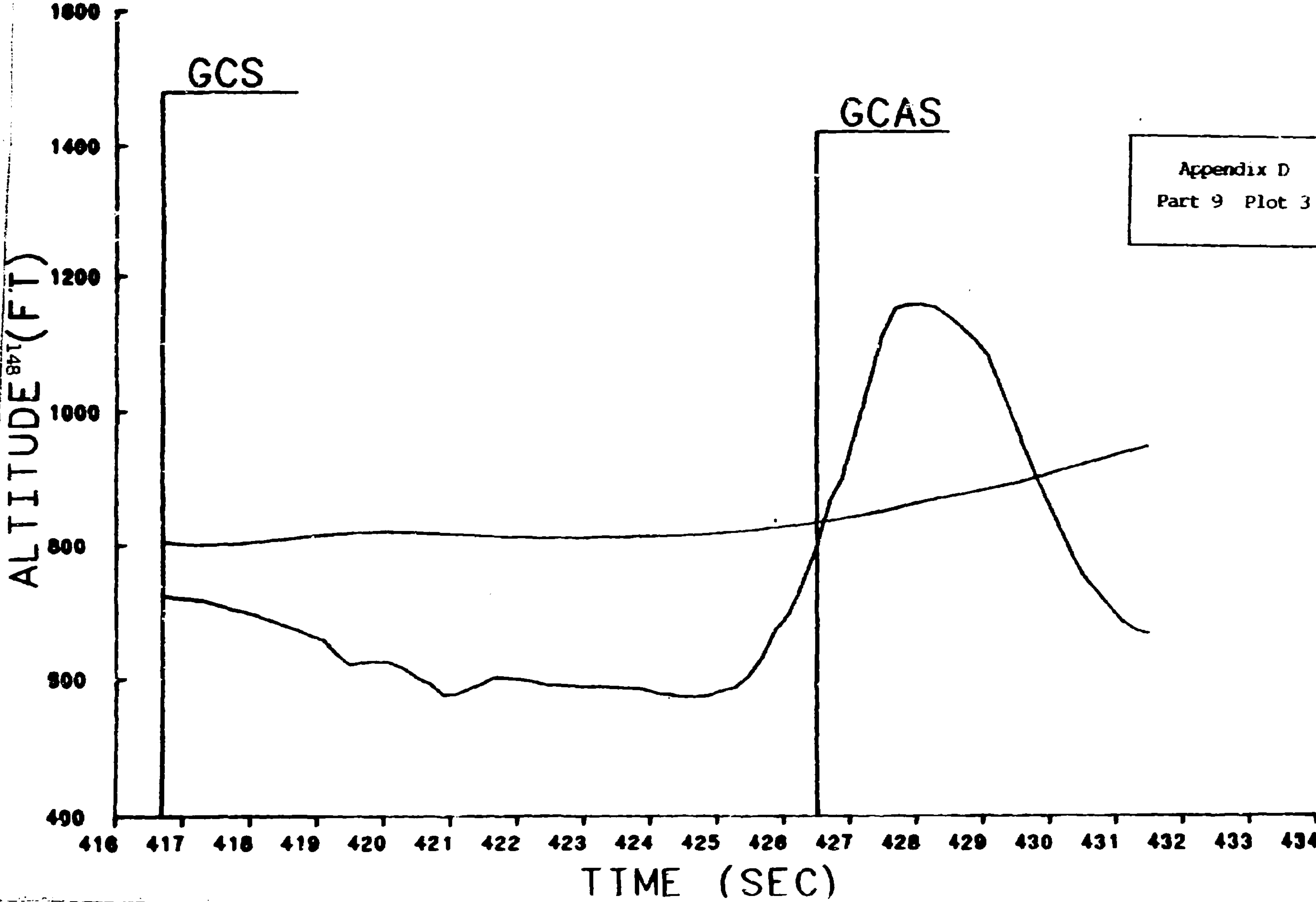


Appendix D
Part 9 Plot 2

LAWS MISSION 17 SUBJECT 1

EVENT #3

CAS	814	814	813	814	814	814	814	814	814	814	813	812	811	809	805
FPA	0	1	0	0	0	0	0	0	1	1	1	1	2	2	2
ROLL	−5	−4	−4	−4	−3	−3	−3	−3	0	7	26	50	61	69	76
G	1.5	1.0	0.9	0.8	1.1	1.1	1.0	1.1	1.1	1.2	1.2	1.5	2.4	2.8	3.0

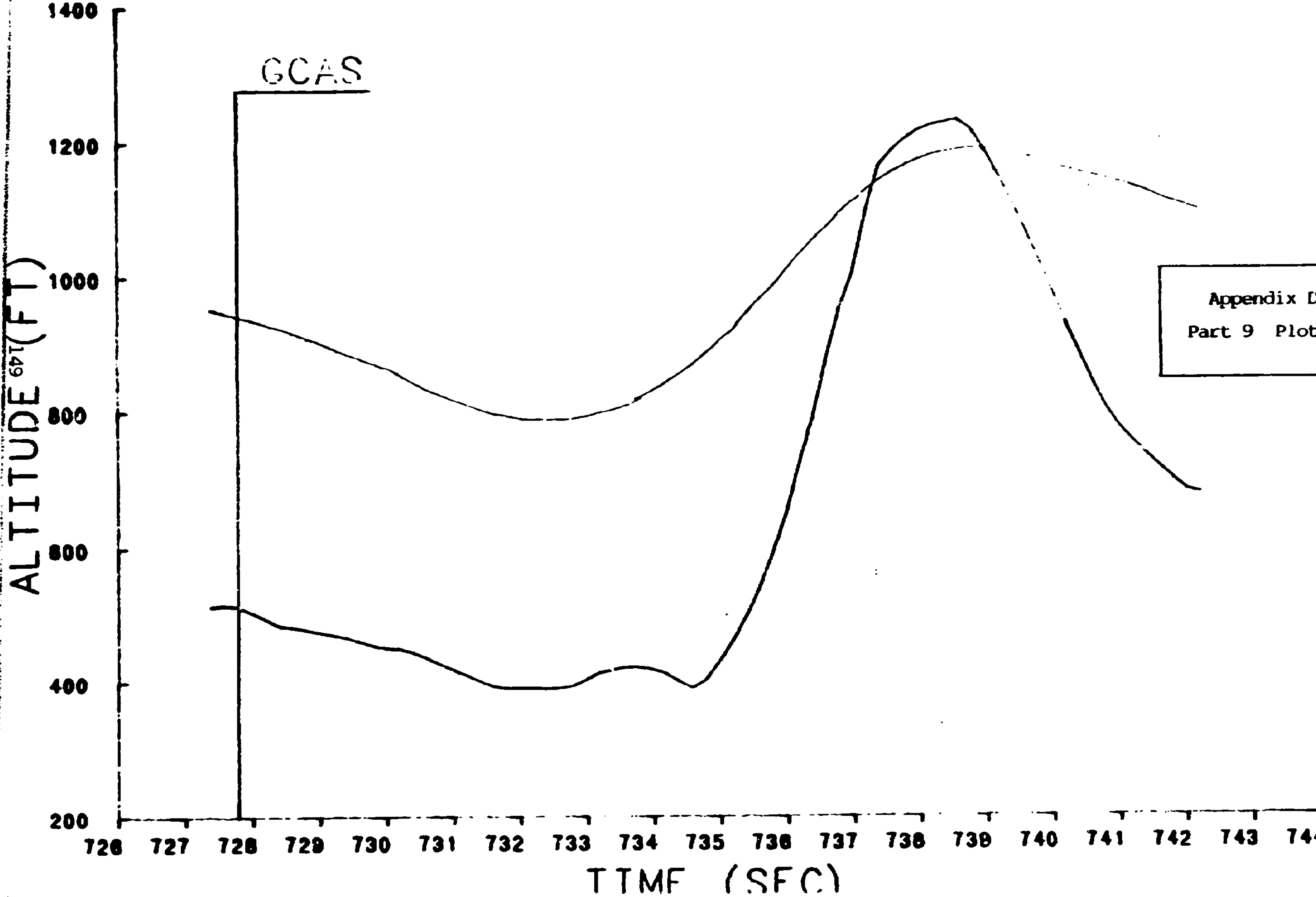


Appendix D
Part 9 Plot 3

LAWS MISSION 17 SUBJECT 1

EVENT #4

CAS	863	862	860	860	858	855	853	847	841	837	834	833	833	833	834
FPA	−2	−3	−3	−3	−1	2	4	7	8	5	2	−2	−1	−2	−3
ROLL	70	69	69	28	6	−2	−3	0	72	109	118	76	−8	1	—
G	2.3	2.4	2.4	1.9	1.8	2.4	1.8	2.1	1.3	1.0	1.8	1.3	1.0	0.8	1.0

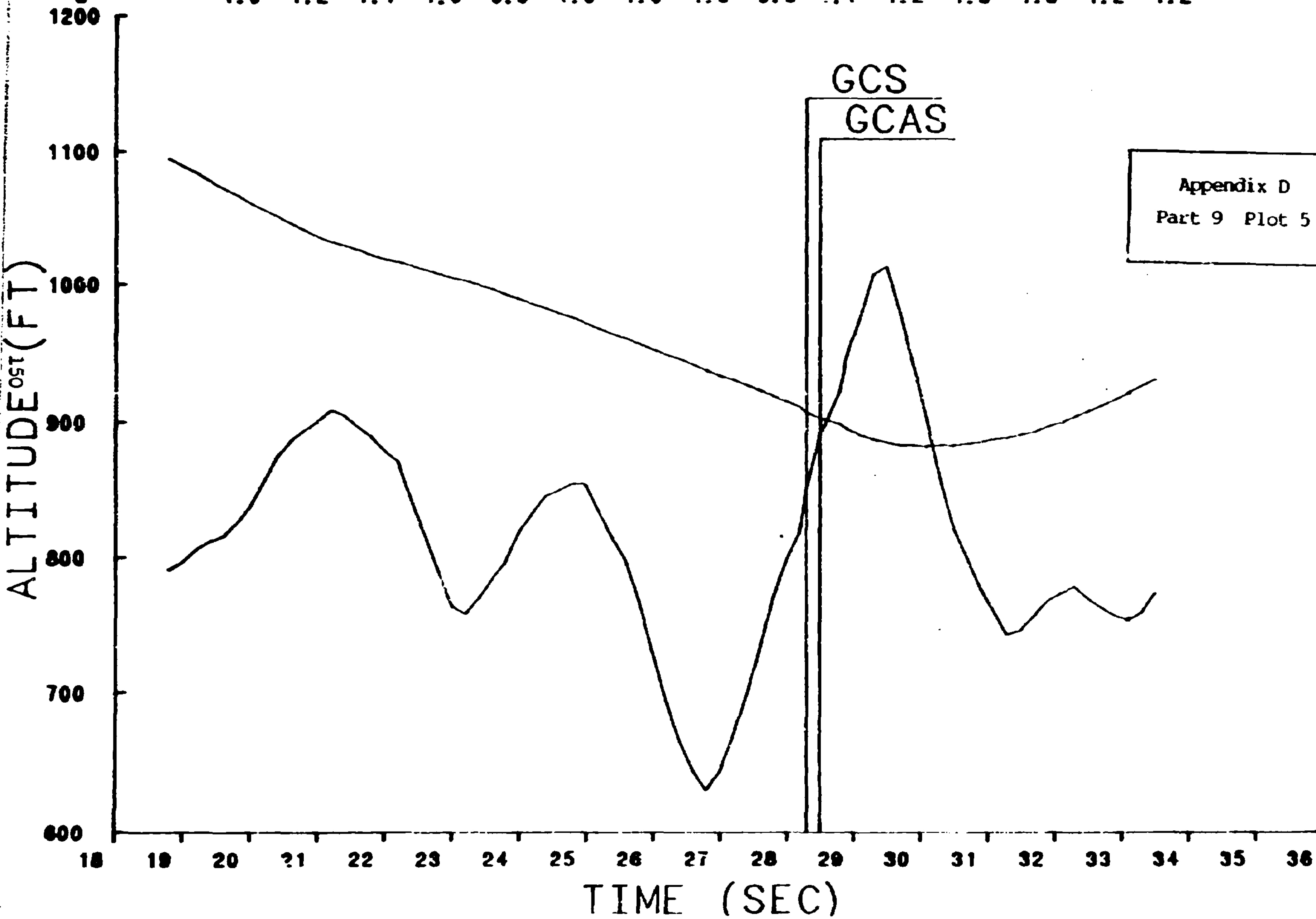


Appendix D
Part 9 Plot 4

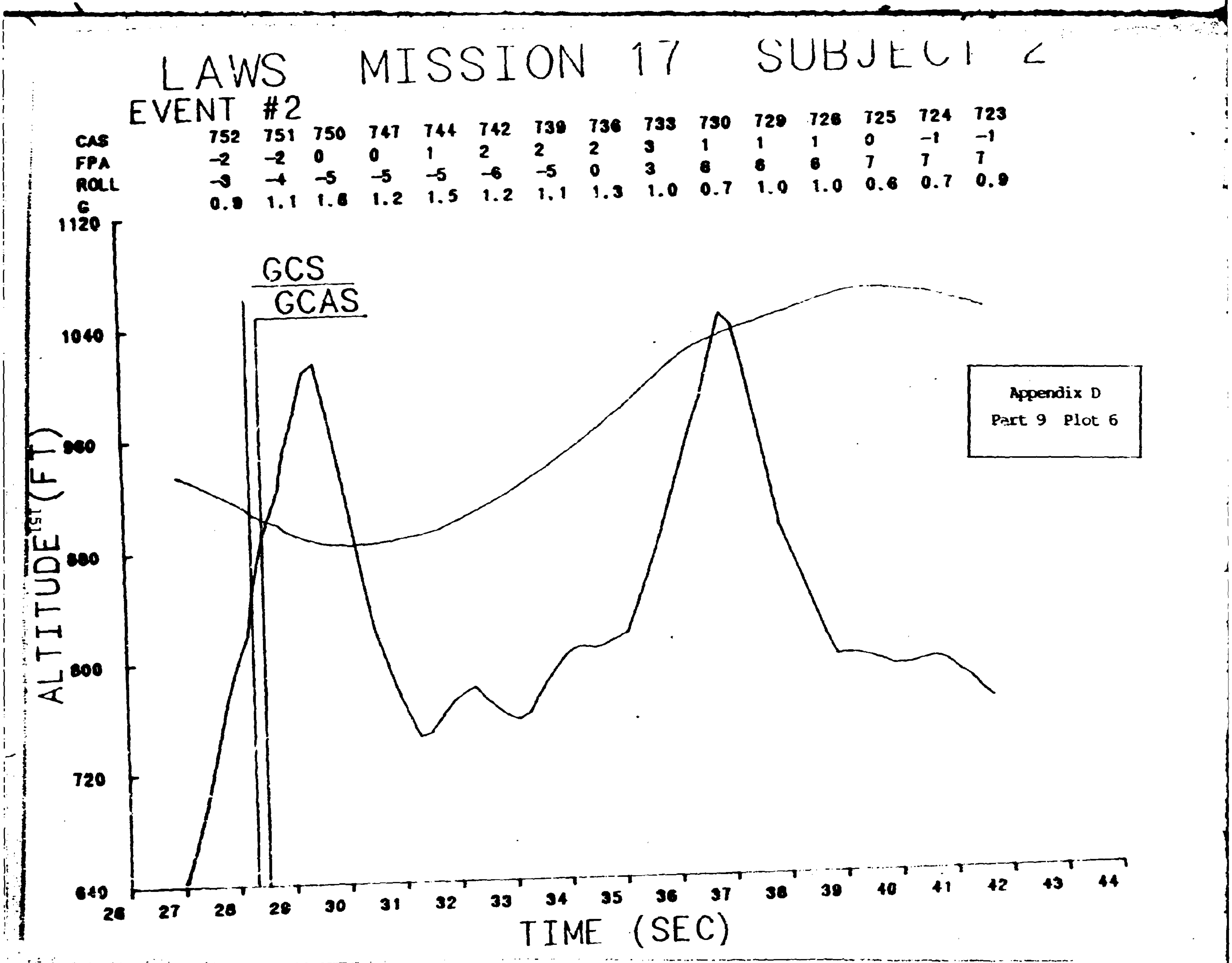
LAWS MISSION 17 SUBJECT 2

EVENT #1

CAS	765	764	762	760	758	757	755	755	753	751	750	747	745	742	739
FPA	-2	-2	-1	-1	-1	-1	-1	-1	-2	-2	-1	0	1	2	2
ROLL	-3	-4	-7	-8	1	2	0	-1	-3	-4	-4	-5	-5	-5	-8
G	1.0	1.2	1.4	1.0	0.9	1.0	1.0	1.0	0.9	1.1	1.2	1.3	1.3	1.2	1.2



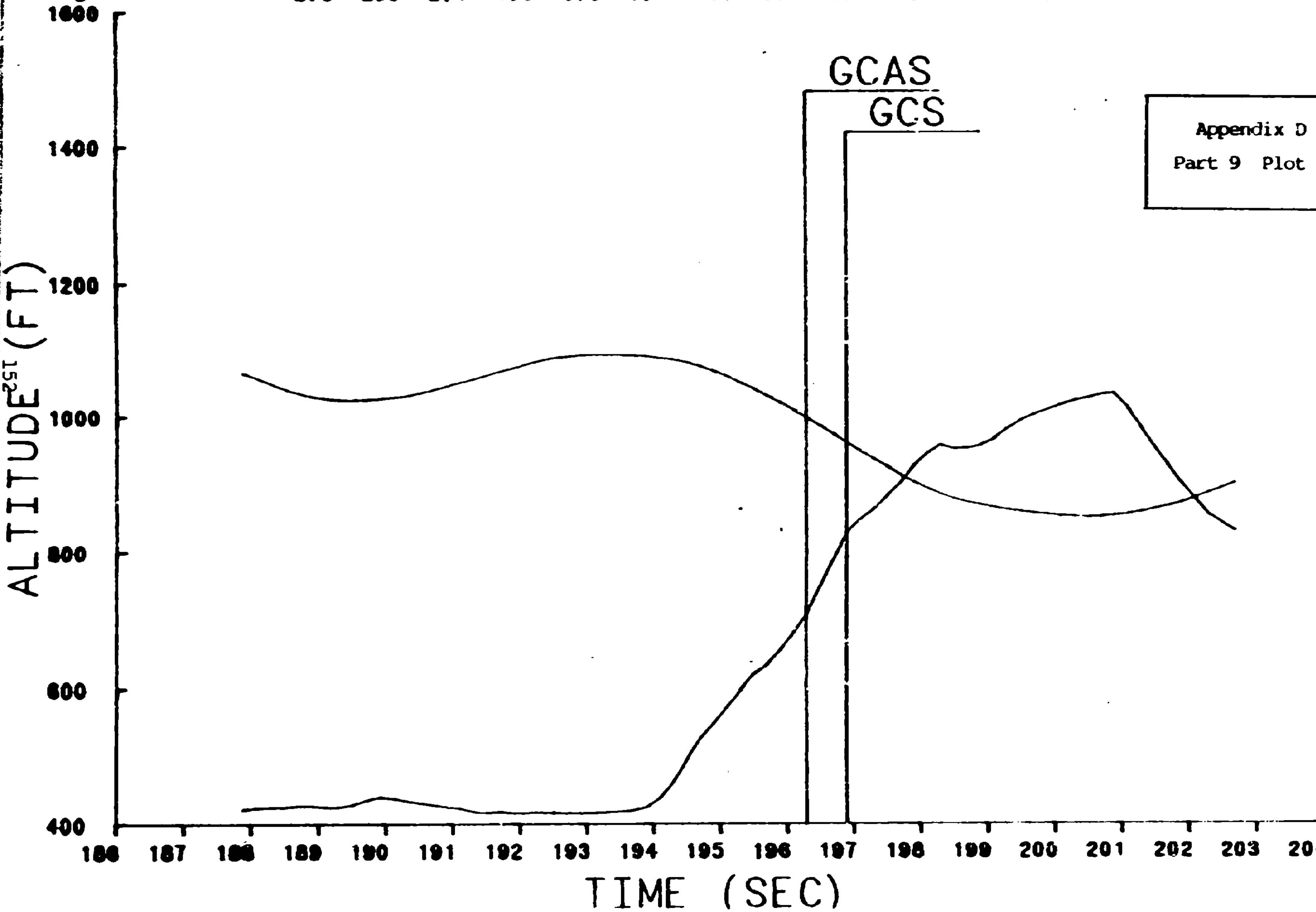
Appendix D
Part 9 Plot 5


LAWS MISSION 17 SUBJECT 2
EVENT #2
CAS 752 751 750 747 744 742 739 736 733 730 729 726 725 724 723
FPA −2 −2 0 0 1 2 2 2 3 1 1 1 0 −1 −1
ROLL −3 −4 −5 −5 −5 −6 −5 0 3 6 6 6 7 7 7
G 0.9 1.1 1.6 1.2 1.5 1.2 1.1 1.3 1.0 0.7 1.0 1.0 0.6 0.7 0.9
GCS
GCAS
ALTITUDE (FT)
1120
1040
960
880
800
720
640
26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44
TIME (SEC)
Appendix D
Part 9 Plot 6

LAWS MISSION 17 SUBJECT 2

EVENT #3

CAS	792	796	800	804	807	814	820	825	833	839	844	848	851	854	855
FPA	−2	0	2	2	1	0	−2	−4	−4	−4	−2	−1	0	2	3
ROLL	34	42	43	43	42	40	34	24	8	−8	−12	−35	−40	−45	−51
G	2.5	2.0	2.1	1.3	0.0	0.7	−0.1	0.8	0.9	1.4	2.5	1.6	2.9	2.8	2.8

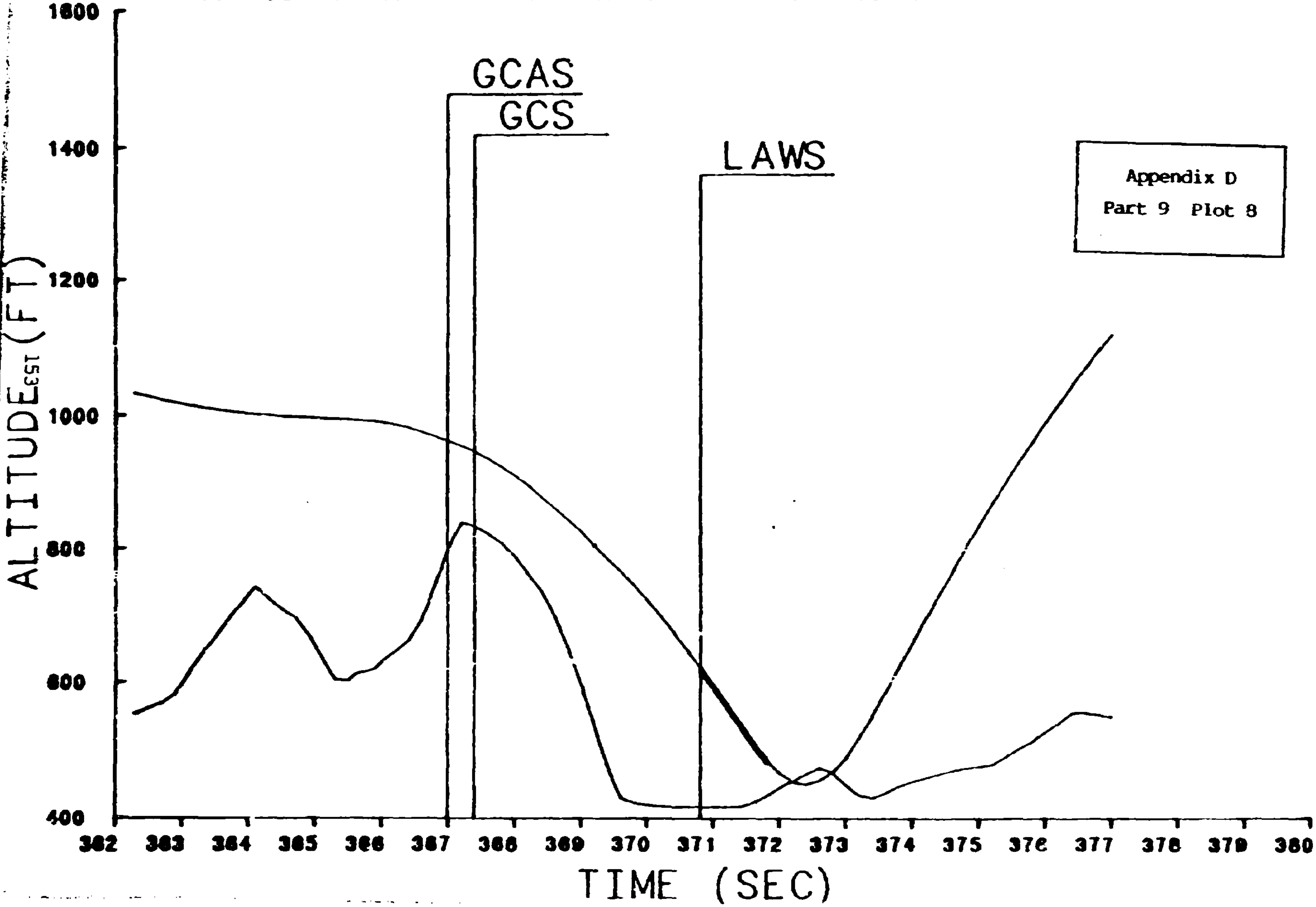


Appendix D
Part 9 Plot 7

LAWS MISSION 17 SUBJECT 2

EVENT #4

CAS	933	934	935	936	937	939	942	941	949	947	932	916	912	908	906
FPA	-1	-1	0	-1	-2	-4	-6	-7	-8	-5	7	11	11	9	8
ROLL	7	1	1	1	2	3	-7	62	80	15	16	72	72	75	76
G	1.3	1.2	1.1	0.2	0.6	-0.5	-0.1	0.7	1.4	6.3	6.0	2.1	1.1	1.0	1.0

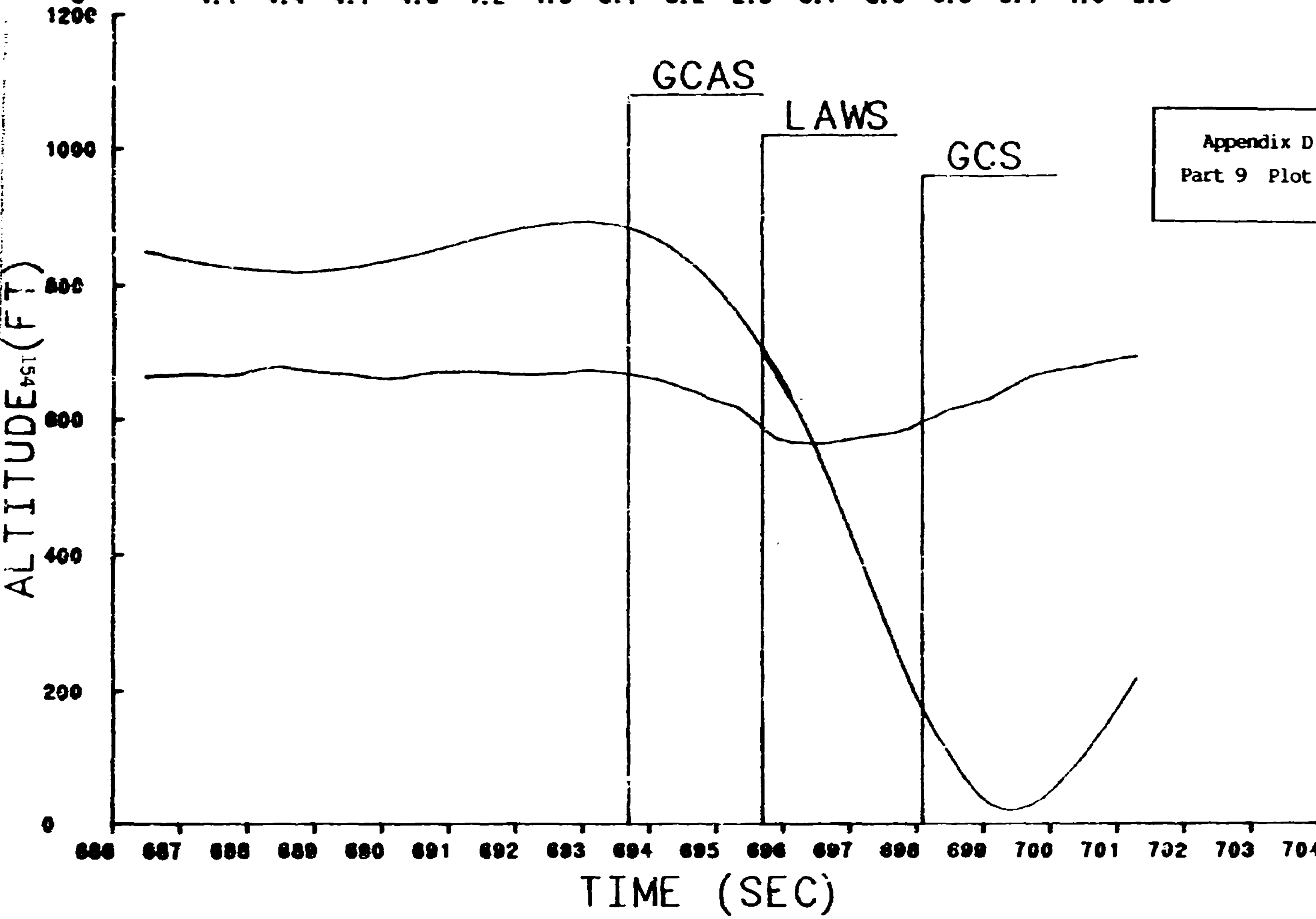


Appendix D
Part 9 Plot 8

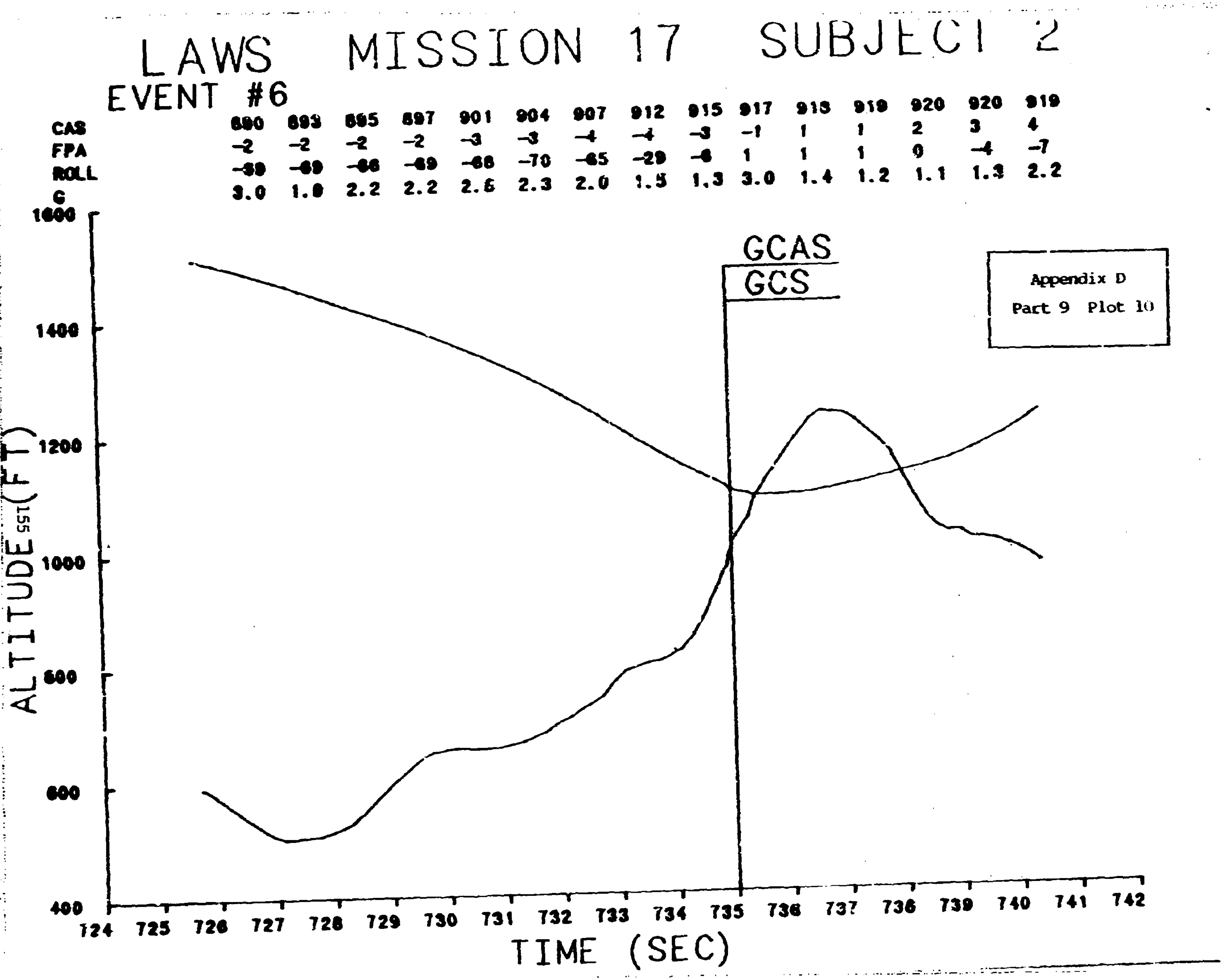
LAWS MISSION 17 SUBJECT 2

EVENT #5

CAS	937	933	929	922	917	912	910	909	913	918	922	915	898	884	880
FPA	-1	-1	1	1	2	1	-1	-4	-8	-13	-16	-11	-2	7	11
ROLL	-69	-74	-70	-73	-78	-82	-93	-106	-120	-127	-81	71	-23	-26	-28
G	4.1	4.4	4.7	4.6	4.2	4.3	3.7	3.2	2.3	3.7	3.3	6.5	9.1	4.9	2.5



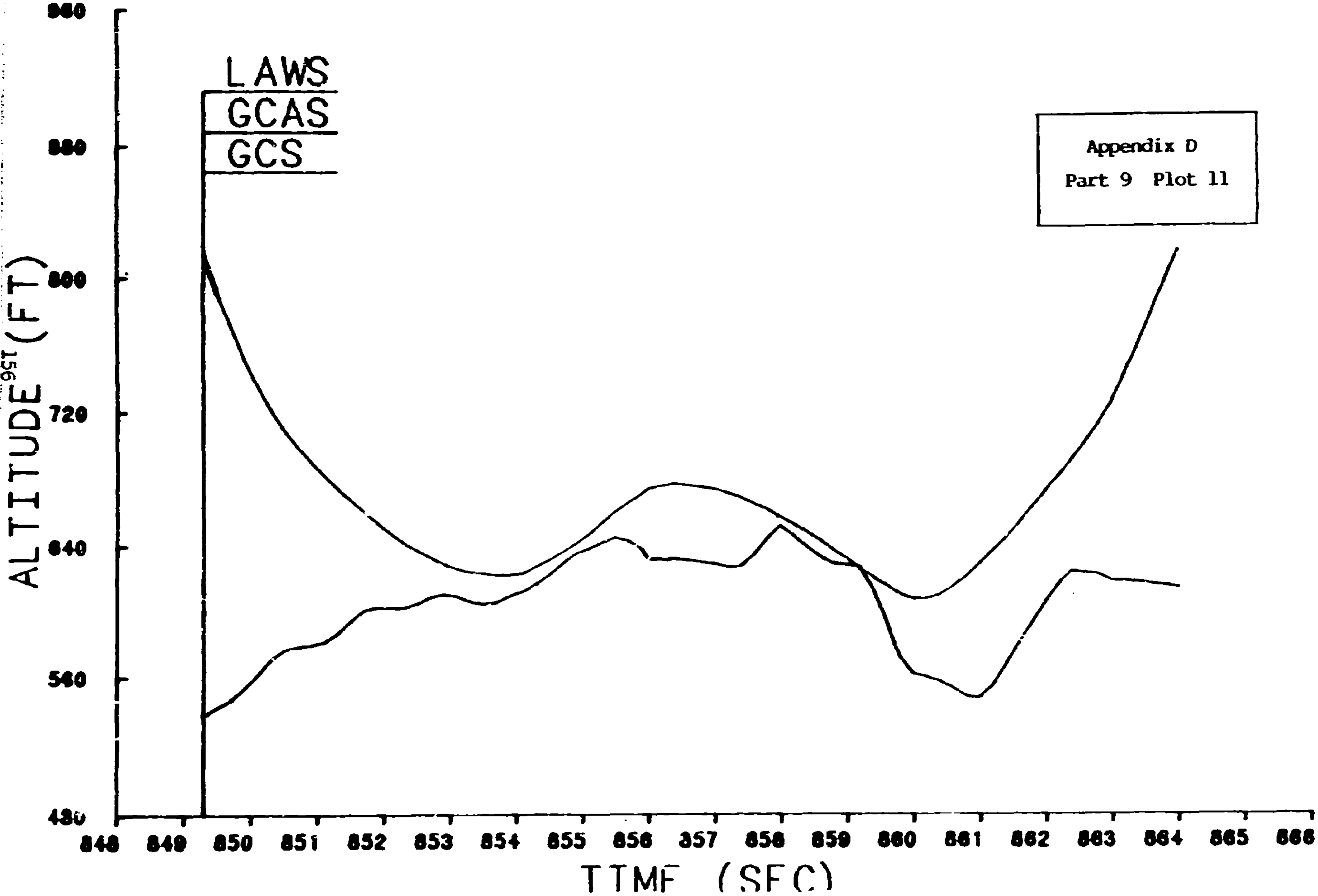
Appendix D
Part 9 Plot 9


LAWS MISSION 17 SUBJECT 2
EVENT #6
CAS 890 893 895 897 901 904 907 912 915 917 918 919 920 920 919
FPA -2 -2 -2 -2 -3 -3 -4 -4 -3 -1 1 1 2 3 4
ROLL -59 -69 -66 -69 -68 -70 -65 -29 -6 1 1 1 0 -4 -7
G 3.0 1.9 2.2 2.2 2.6 2.3 2.0 1.5 1.3 3.0 1.4 1.2 1.1 1.3 2.2
GCAS
GCS
Appendix D
Part 9 Plot 10
1600
1400
1200
1000
800
600
400
ALTITUDE (FT)
724 725 726 727 728 729 730 731 732 733 734 735 736 737 738 739 740 741 742
TIME (SEC)

LAWS MISSION 17 SUBJECT 2

EVENT #7

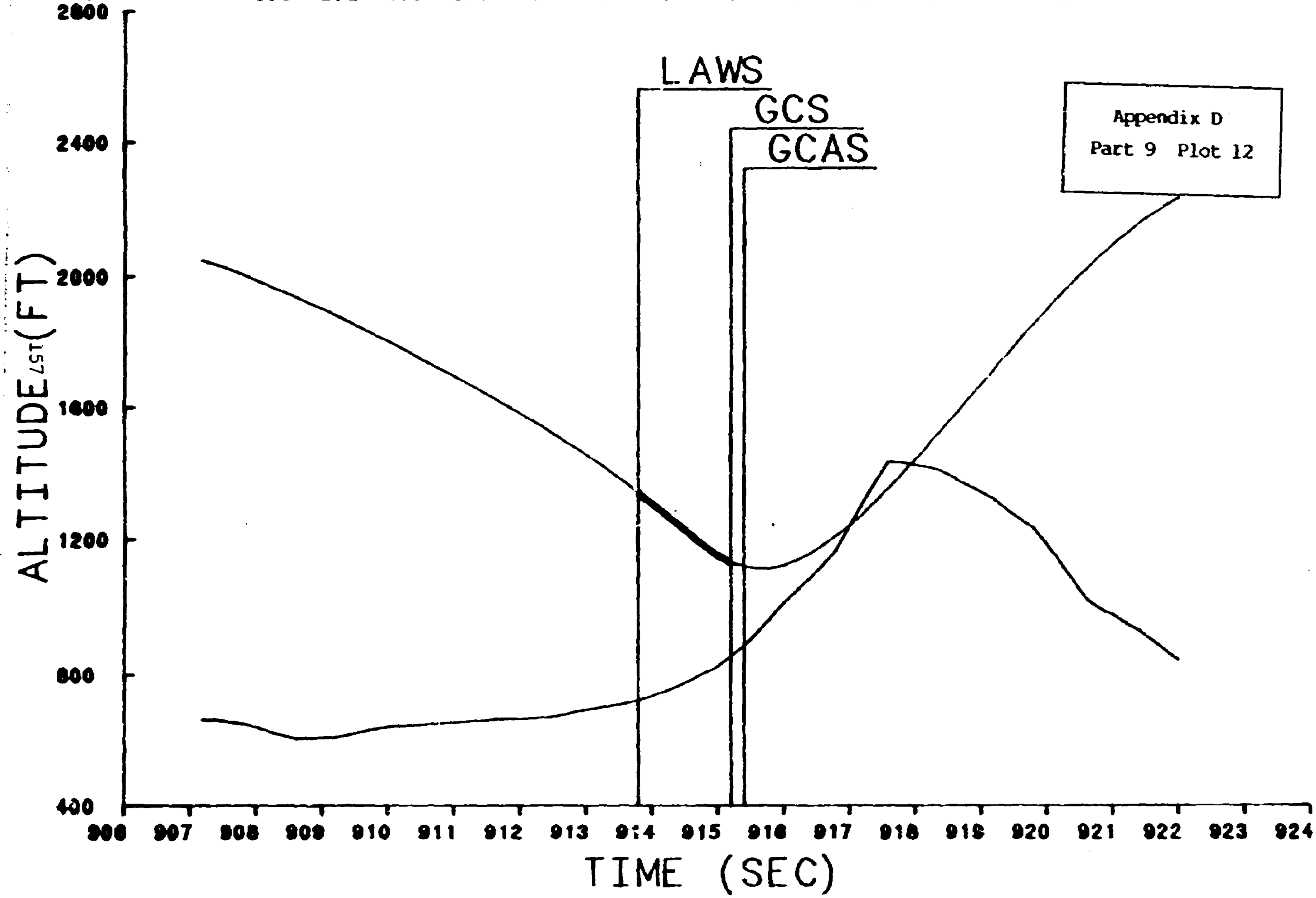
CAS	924	921	923	924	925	925	925	926	928	930	931	930	929	927	925
FPA	-5	-3	-2	-1	1	2	1	-1	-1	-2	-1	2	3	5	8
ROLL	-54	-58	-34	12	10	9	8	4	3	2	-10	-12	-7	-7	-7
G	5.0	2.8	1.9	1.8	2.4	1.4	-0.1	0.5	0.7	0.8	1.8	1.8	1.2	3.5	1.4

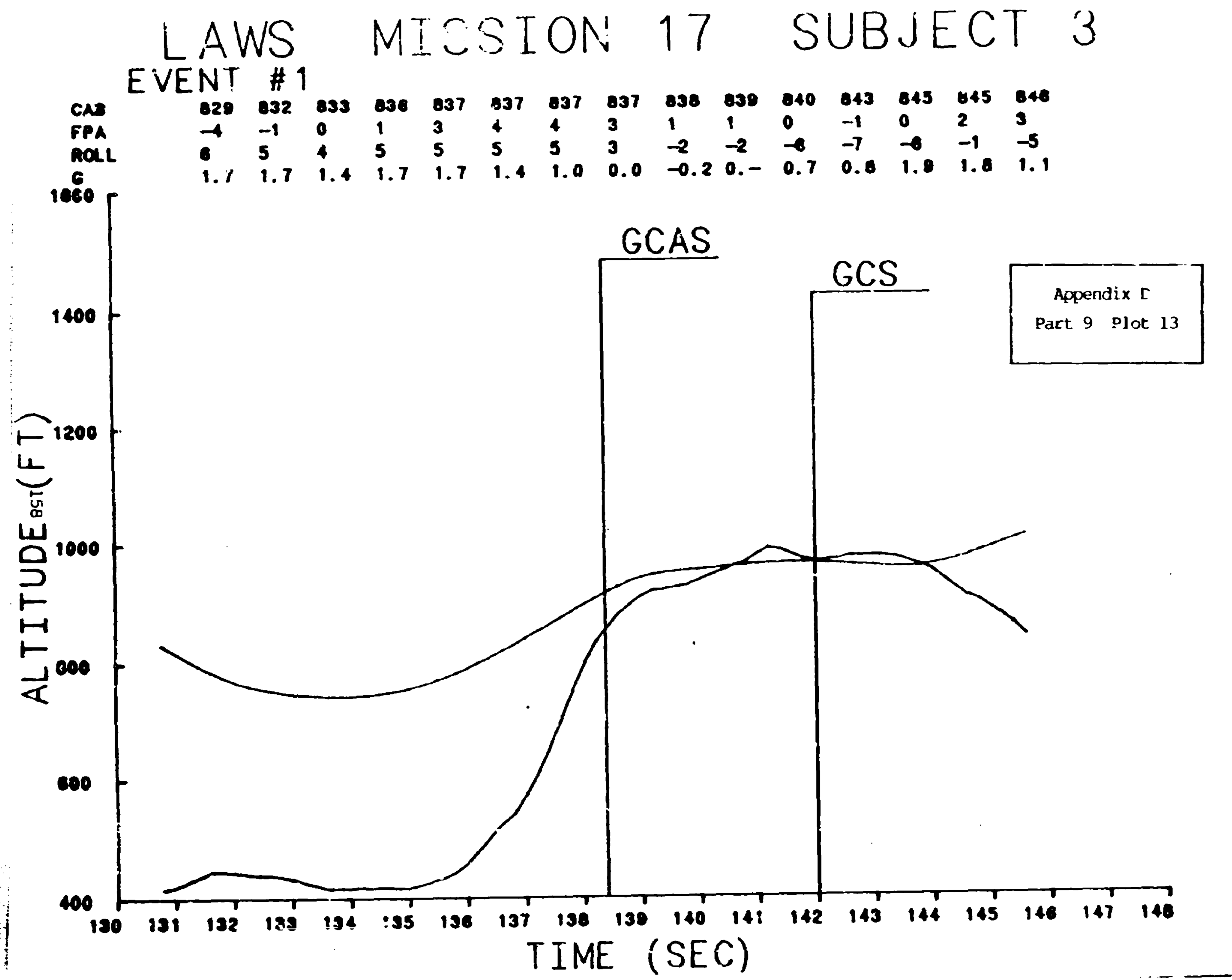


LAWS MISSION 17 SUBJECT 2

EVENT #8

CAS	903	908	910	915	916	916	909	888	860	833	817	805	802	796	792
FPA	-5	-6	-7	-7	-8	-9	-10	-9	3	11	16	17	16	12	8
ROLL	-71	-73	-74	-76	-81	-86	-85	-46	1	-81	-83	-81	-53	-43	-50
G	0.9	2.2	2.9	3.5	4.4	4.5	7.7	9.1	8.1	7.4	4.1	1.6	-0.1	-0.8	-1.3



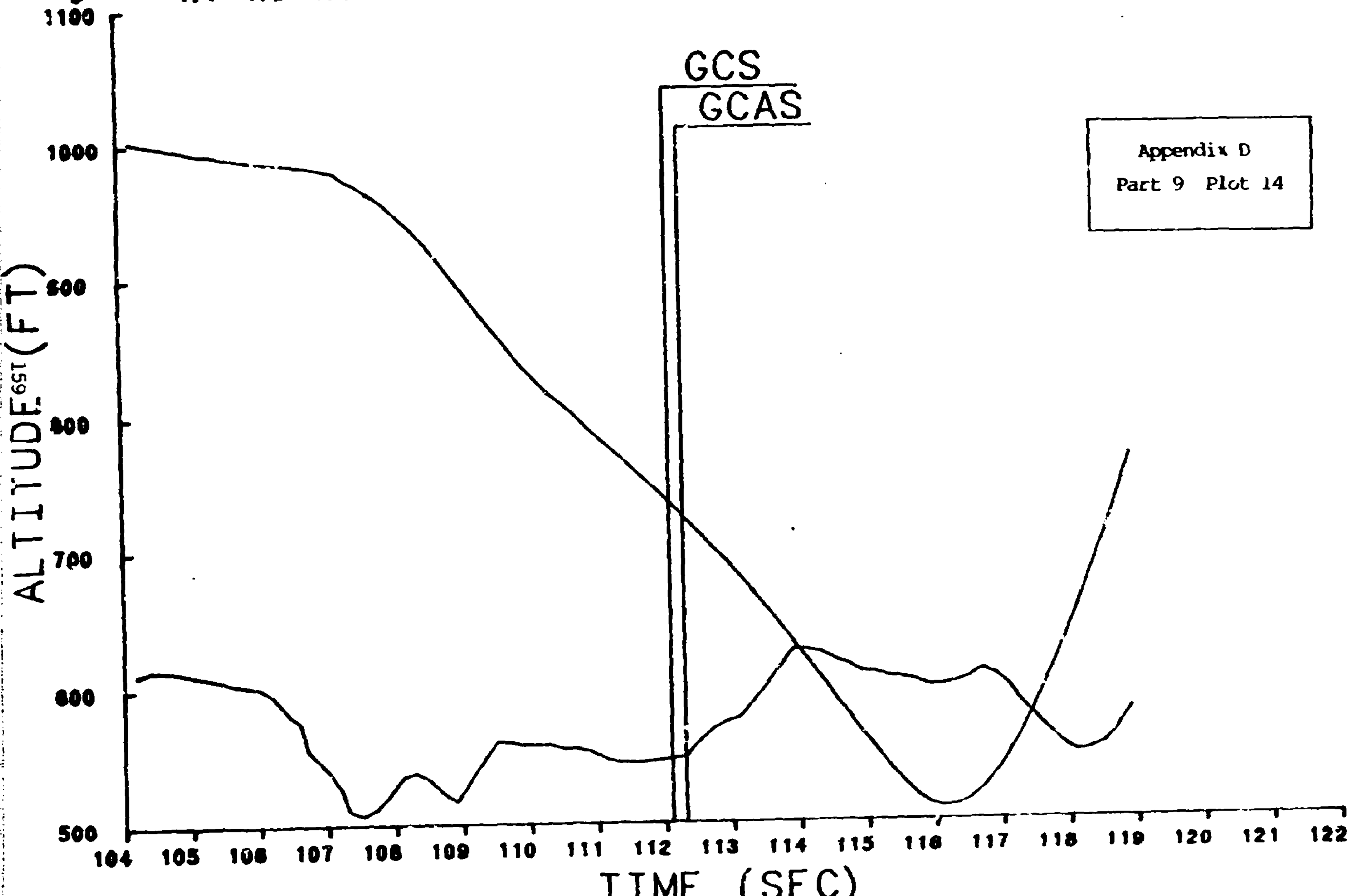


LAWS MICSION 17 SUBJECT 3
EVENT #1
CAS 829 832 833 836 837 837 837 837 838 839 840 843 845 845 848
FPA -4 -1 0 1 3 4 4 3 1 1 0 -1 0 2 3
ROLL 6 5 4 5 5 5 5 3 -2 -2 -6 -7 -6 -1 -5
G 1.7 1.7 1.4 1.7 1.7 1.4 1.0 0.0 -0.2 0.- 0.7 0.6 1.9 1.8 1.1
GCAS
GCS
Appendix D
Part 9 Plot 13
ALTITUDE BST (FT)
1600
1400
1200
1000
800
600
400
130
131
132
133
134
135
136
137
138
139
140
141
142
143
144
145
146
147
148
TIME (SEC)

LAWS MISSION 17 SUBJECT 4

EVENT #1

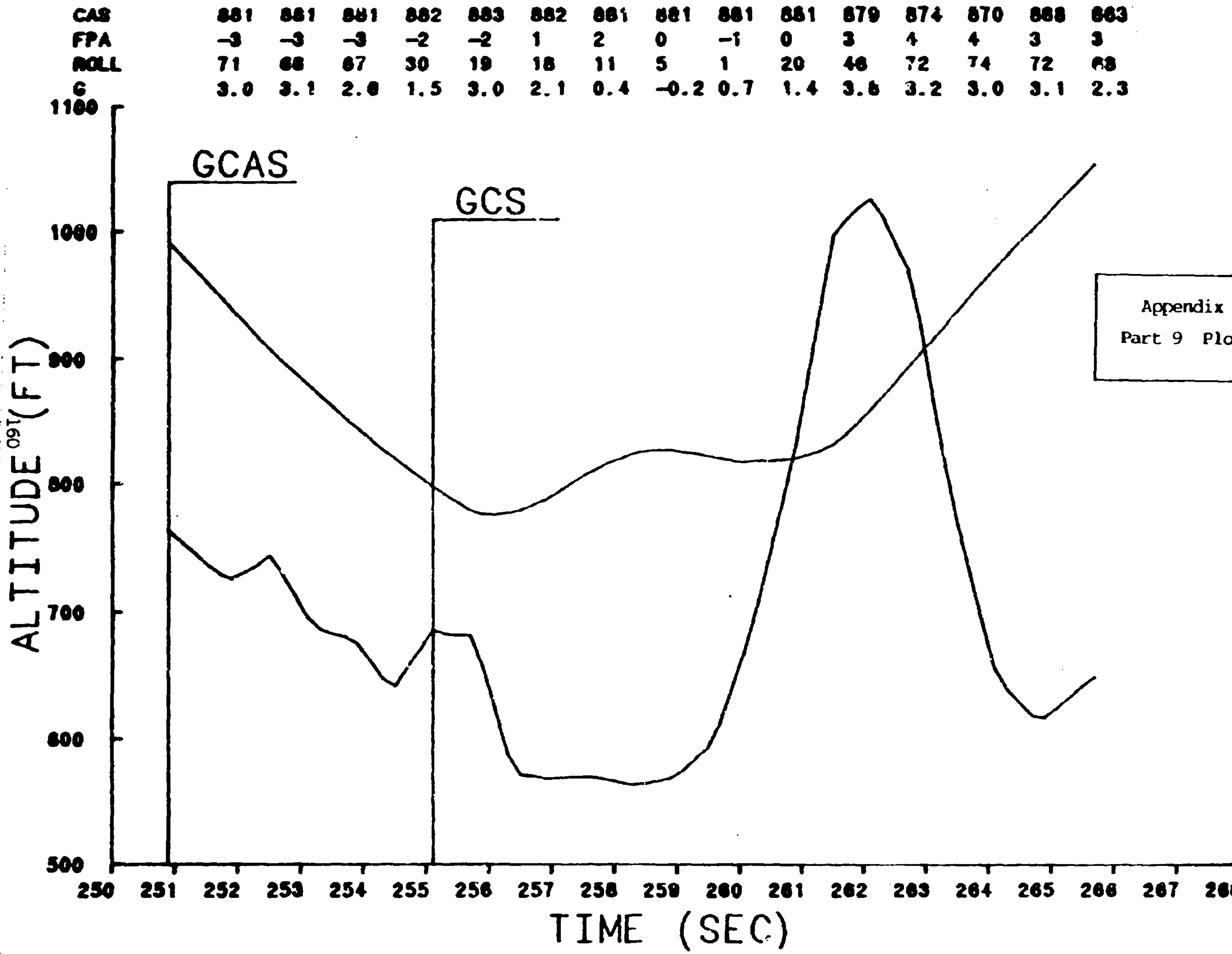
CAS	866	869	870	870	863	848	835	828	827	830	833	834	828	825	821
FPA	−1	0	−1	−3	−4	−4	−3	−3	−4	−4	−4	−2	4	8	11
ROLL	−3	18	86	88	65	76	80	79	78	74	63	27	12	6	3
G	1.1	1.2	1.8	3.0	6.0	6.1	6.1	4.2	2.9	2.4	2.8	3.3	3.5	2.2	2.7



Appendix D
Part 9 Plot 14

LAWS MISSION 17 SUBJECT 4

EVENT #2



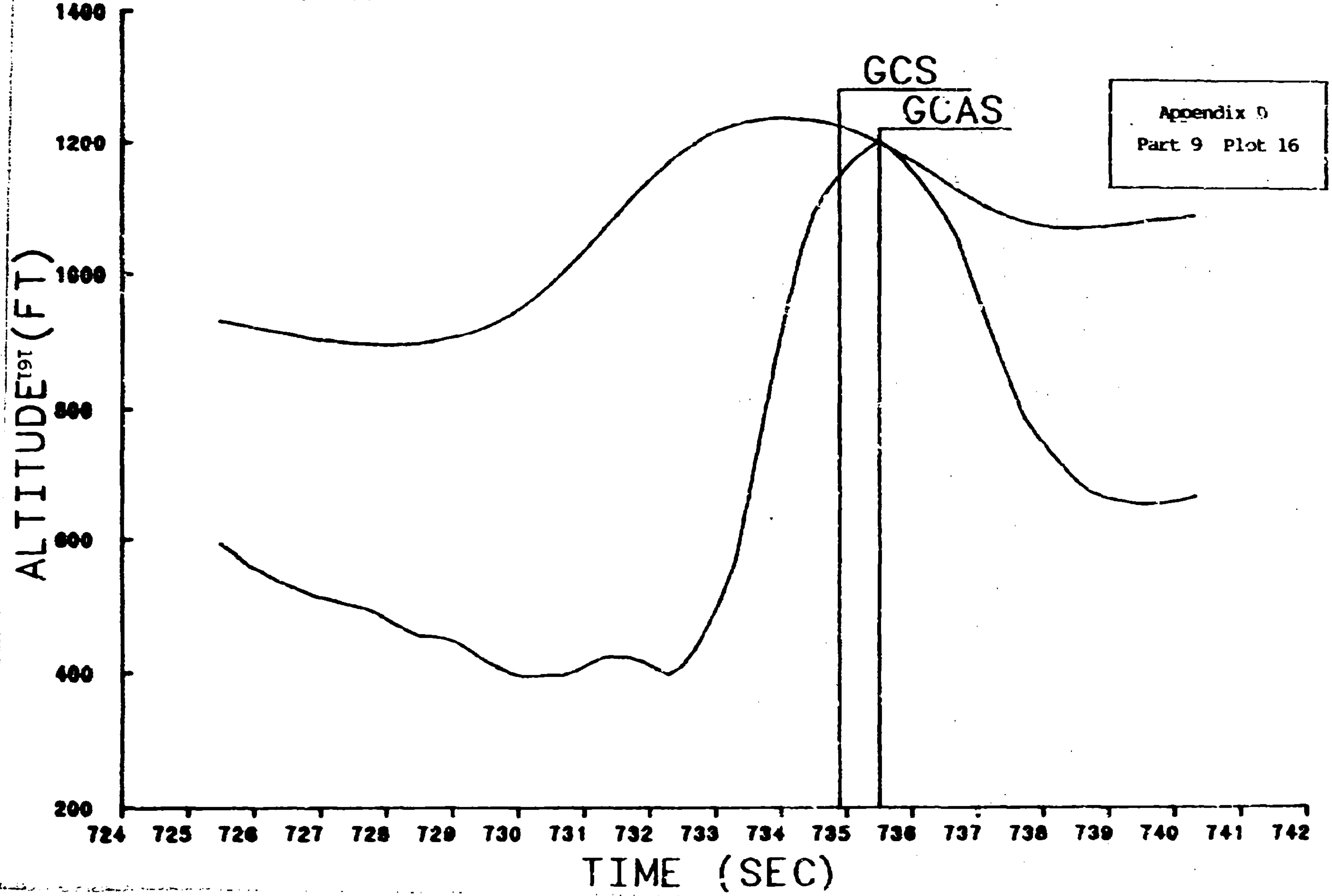
Appendix D

Part 9 Plot 15

LAWS MISSION 17 SUBJECT 4

EVENT #3

CAS	933	934	934	933	930	926	923	918	916	919	921	923	923	923	923
FPA	−1	−1	0	2	5	7	5	2	0	−3	−4	−3	0	1	0
ROLL	9	3	0	−1	−3	−3	3	38	52	59	54	35	22	19	16
G	1.0	1.3	1.8	1.5	2.6	1.6	−0.1	−1.1	−0.1	0.0	1.1	2.4	2.1	1.4	0.4

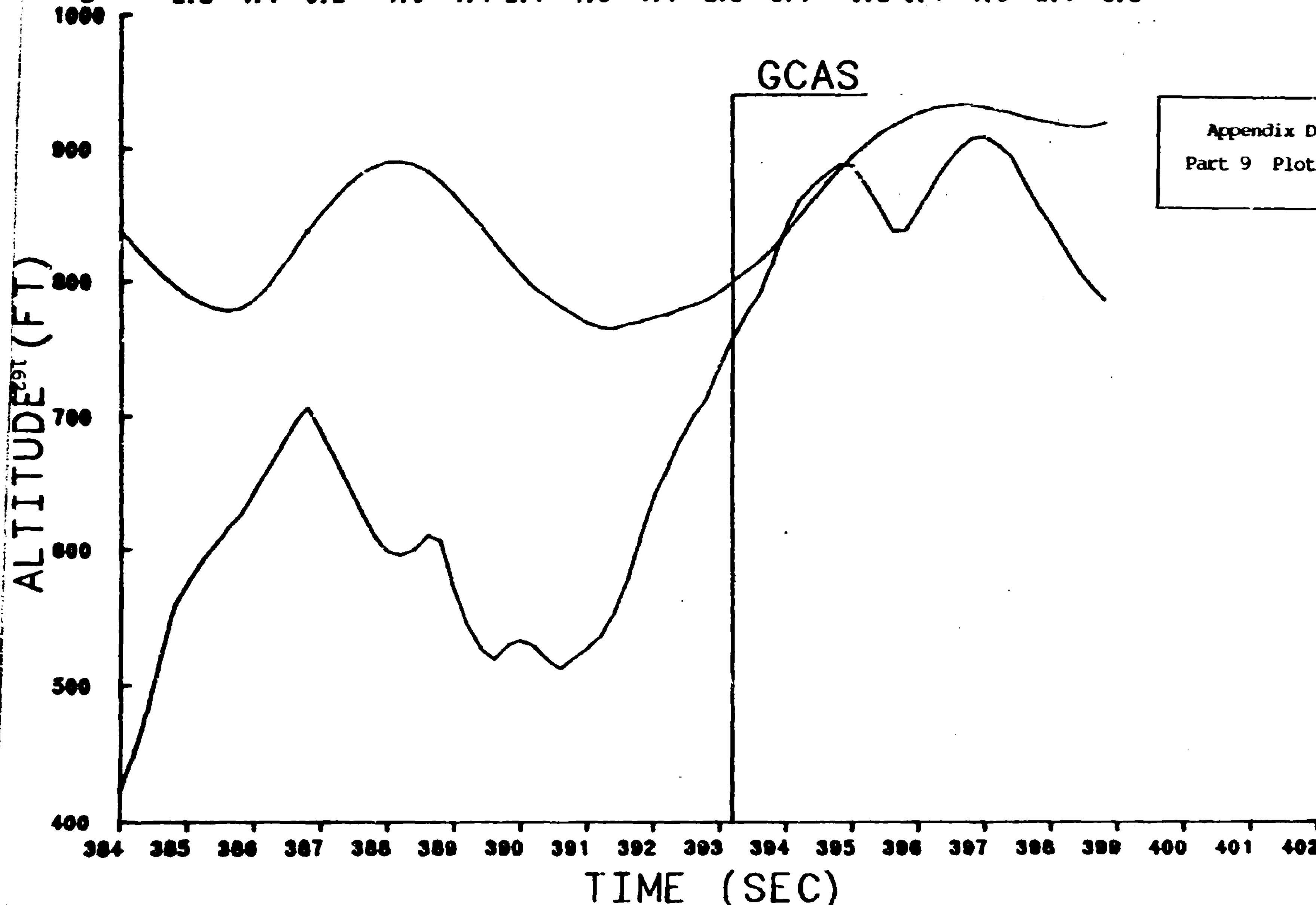


Appendix 9
Part 9 Plot 16

LAWS MISSION 17 SUBJECT 5

EVENT #1

CAS	910	911	909	906	904	908	911	912	913	912	910	911	913	914	915
FPA	−3	1	4	2	−3	−4	−2	1	2	3	3	2	0	−1	1
ROLL	44	15	4	−15	−40	−34	−22	−22	−33	−44	−61	−61	−78	−62	−28
G	2.8	4.4	0.2	−1.0	−1.4	2.1	1.3	1.1	2.9	5.1	−0.2	0.4	1.3	2.1	3.6



Appendix D
Part 9 Plot 17

LAWS MISSION 17 SUBJECT 6

EVENT #1

CAS	749	776	810	844	874	907	941	973	993	988	982
FPA	-11	-20	-22	-25	-29	-31	-34	-39	-32	-41	-47
ROLL	179	123	80	35	-19	-84	126	128	-38	179	-5
G	3.4	2.1	0.5	-0.7	-1.4	2.2	1.9	1.8	7.6	9.2	8.4

Appendix D
Part 9 Plot 18